HHI WS@BNL,
March 1, 2012

Recent topics in Hypernuclear physics and Perspective at J-PARC

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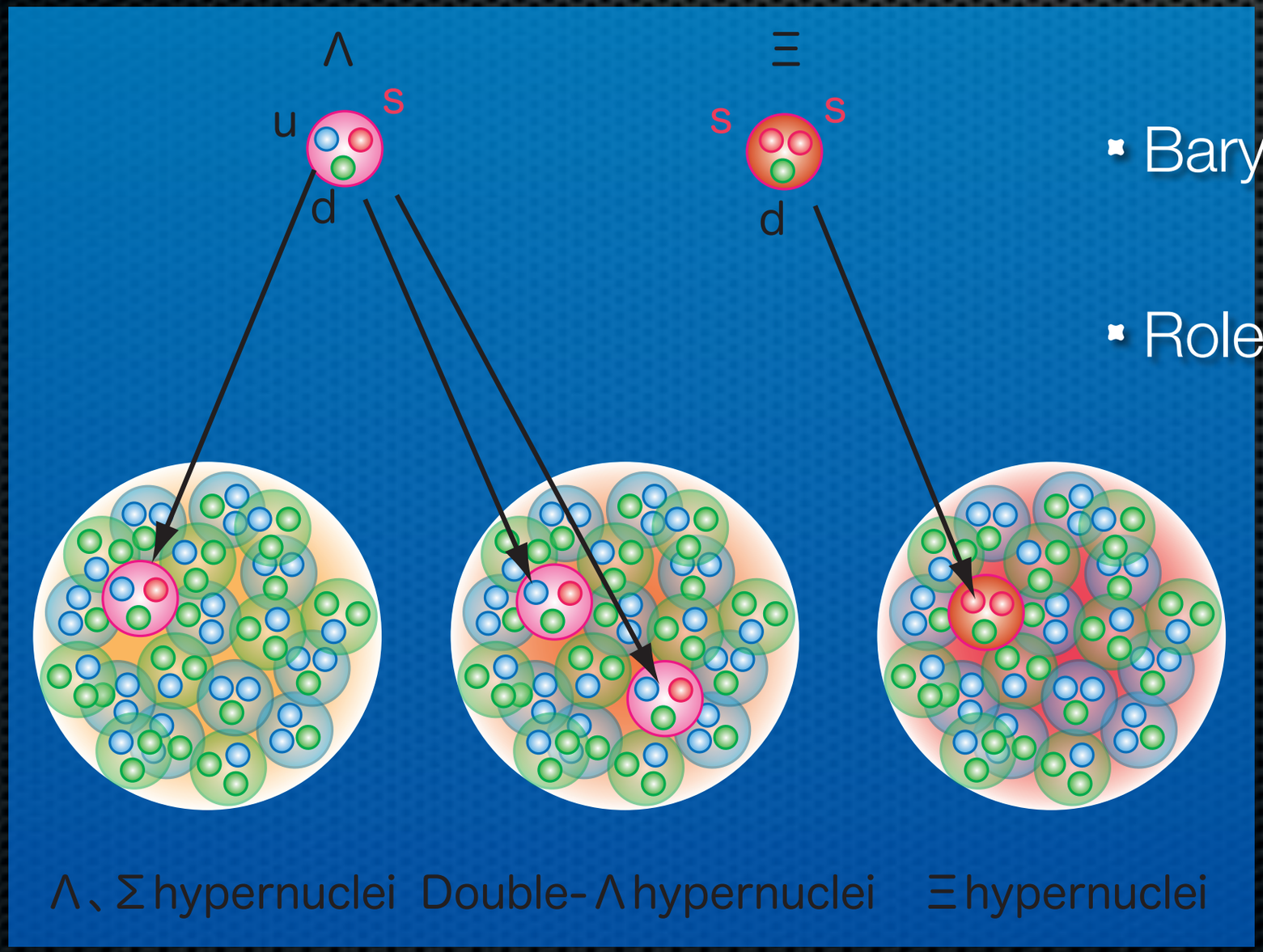
Kyoto University

Contents

- Introduction to Strangeness Nuclear Physics
- Recent Topics and Perspective in Strangeness Nuclear Physics
  - S=-1 Baryon Systems
  - S=-2 Baryon Systems
  - Kaonic Nuclei
- Summary

Hadron Many-Body Systems with Strangeness

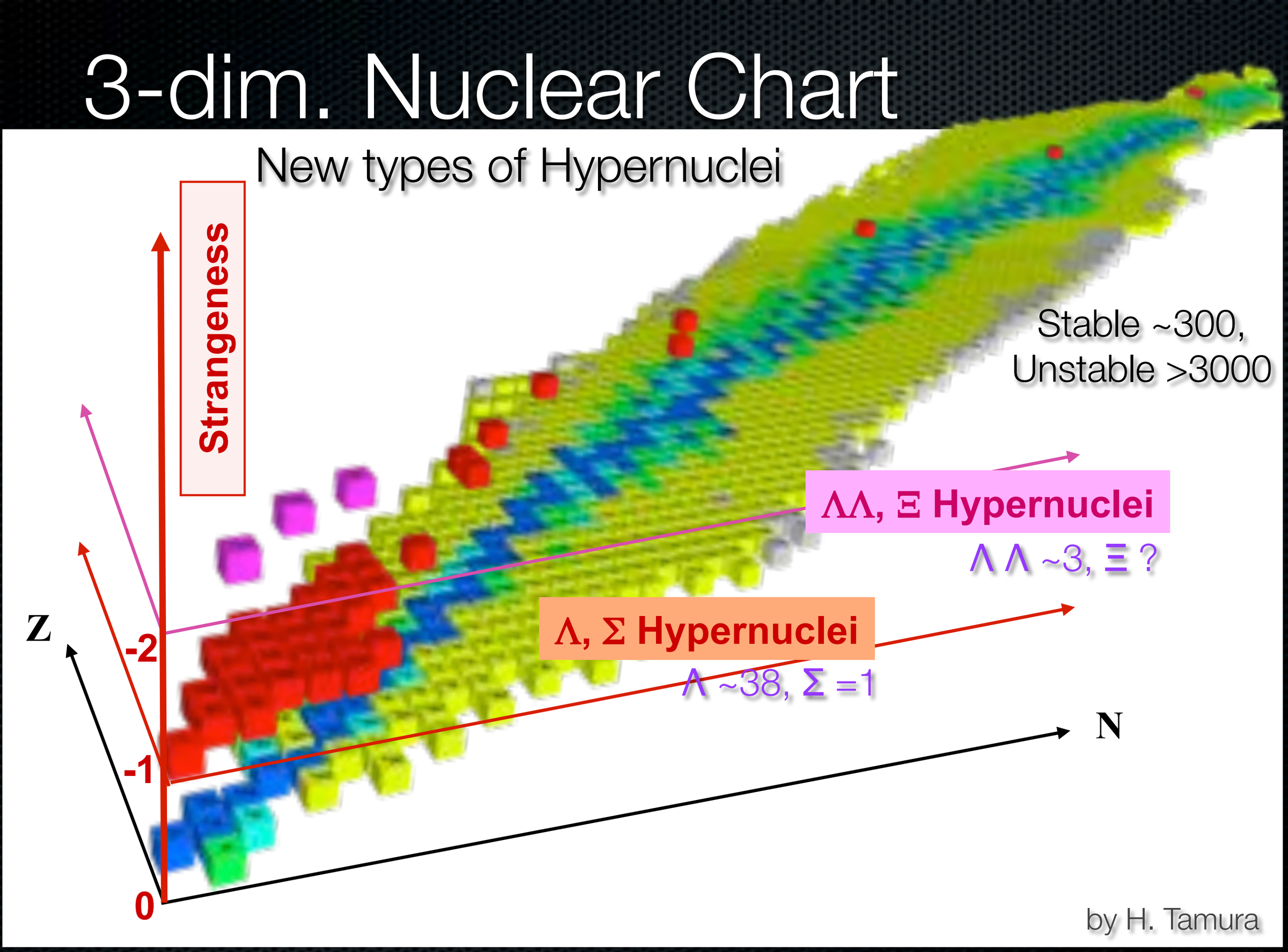
- Hypernuclei : Hyperons(Λ, Σ, Ξ) in Nuclei



- Baryon-Baryon Interactions in $SU_F(3)$
- Role of Strangeness in Dense Matter

3-dim. Nuclear Chart

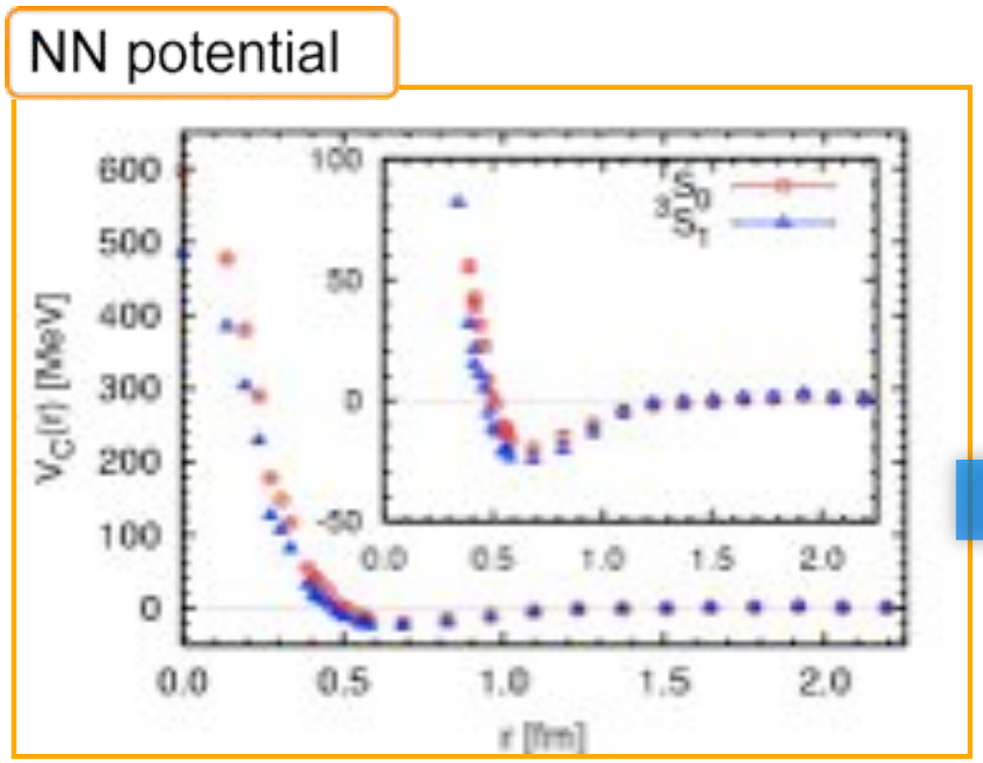
New types of Hypernuclei



by H. Tamura

Modern Picture of Baryon-Baryon Interactions

- Nuclear Force from Lattice QCD

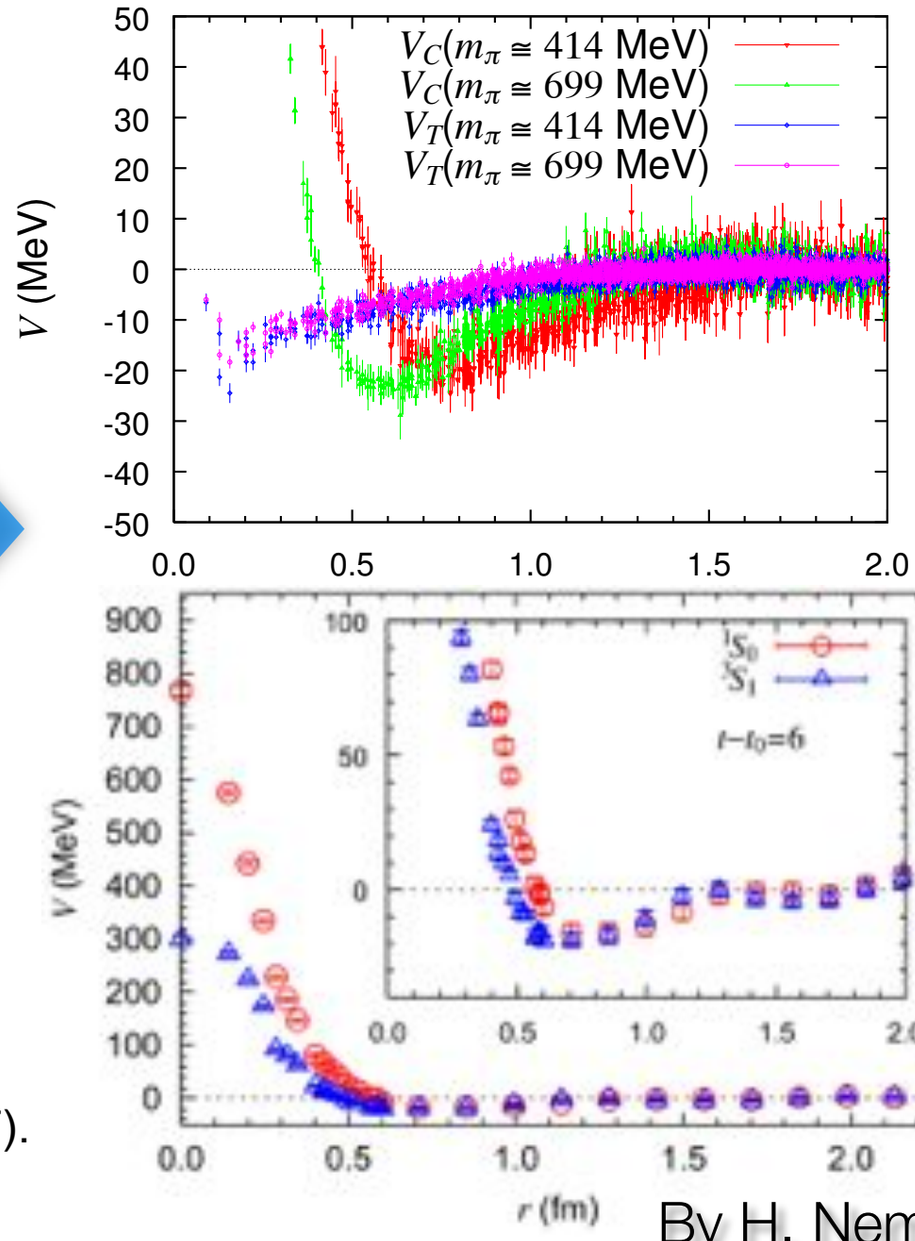


Long-range attraction

+

Repulsive Hard-core

N.Ishii, S.Aoki, T.Hatsuda, Phys.Rev.Lett.99,022001 (2007).



By H. Nemura et al.

World Facilities in the 21st Century

For Strangeness Nuclear Physics

J-PARC Facility (KEK/JAEA)

South to North

Linac

3 GeV Synchrotron

Neutrino Beams (to Kamioka)

50 GeV Synchrotron

Materials and Life Experimental Facility

Hadron Exp. Facility

CY2007 Beams
JFY2008 Beams
JFY2009 Beams

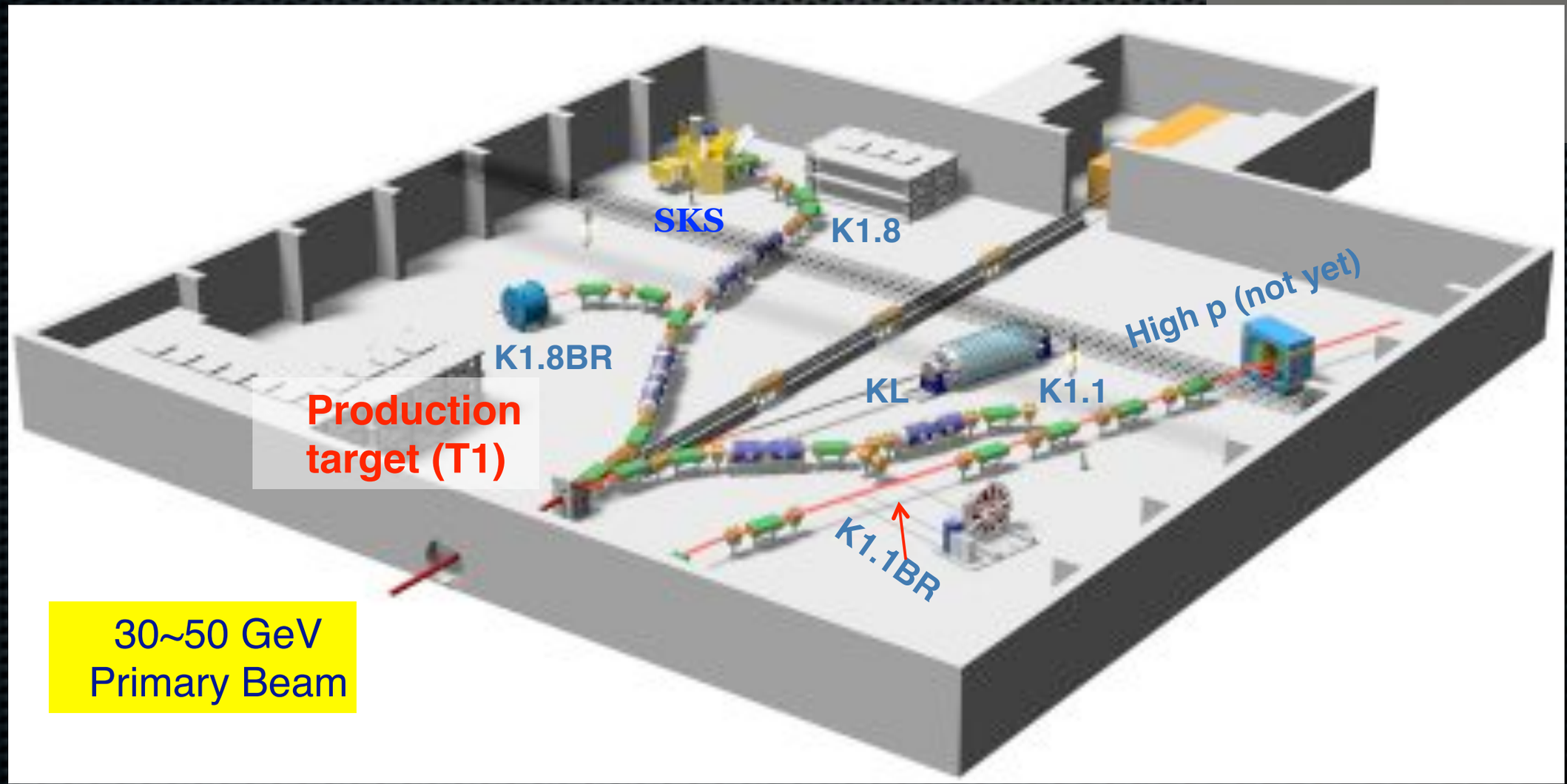
Photo in July of 2009

Hadron Experimental Hall

World highest intensity Kaon beams !

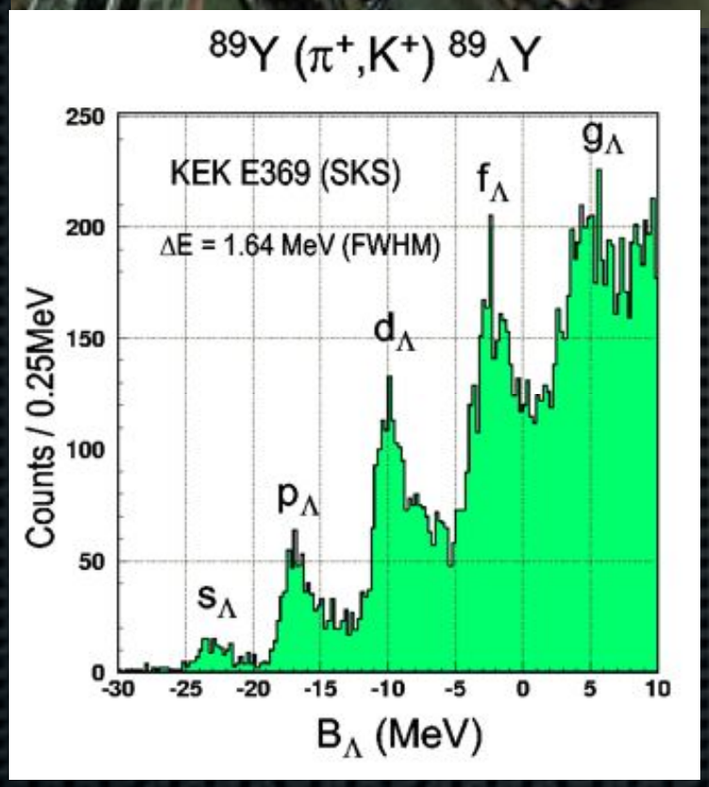
First beam in Feb. 2009
Beam recovery in Feb. 2012 after the Earthquake

60m x 56m



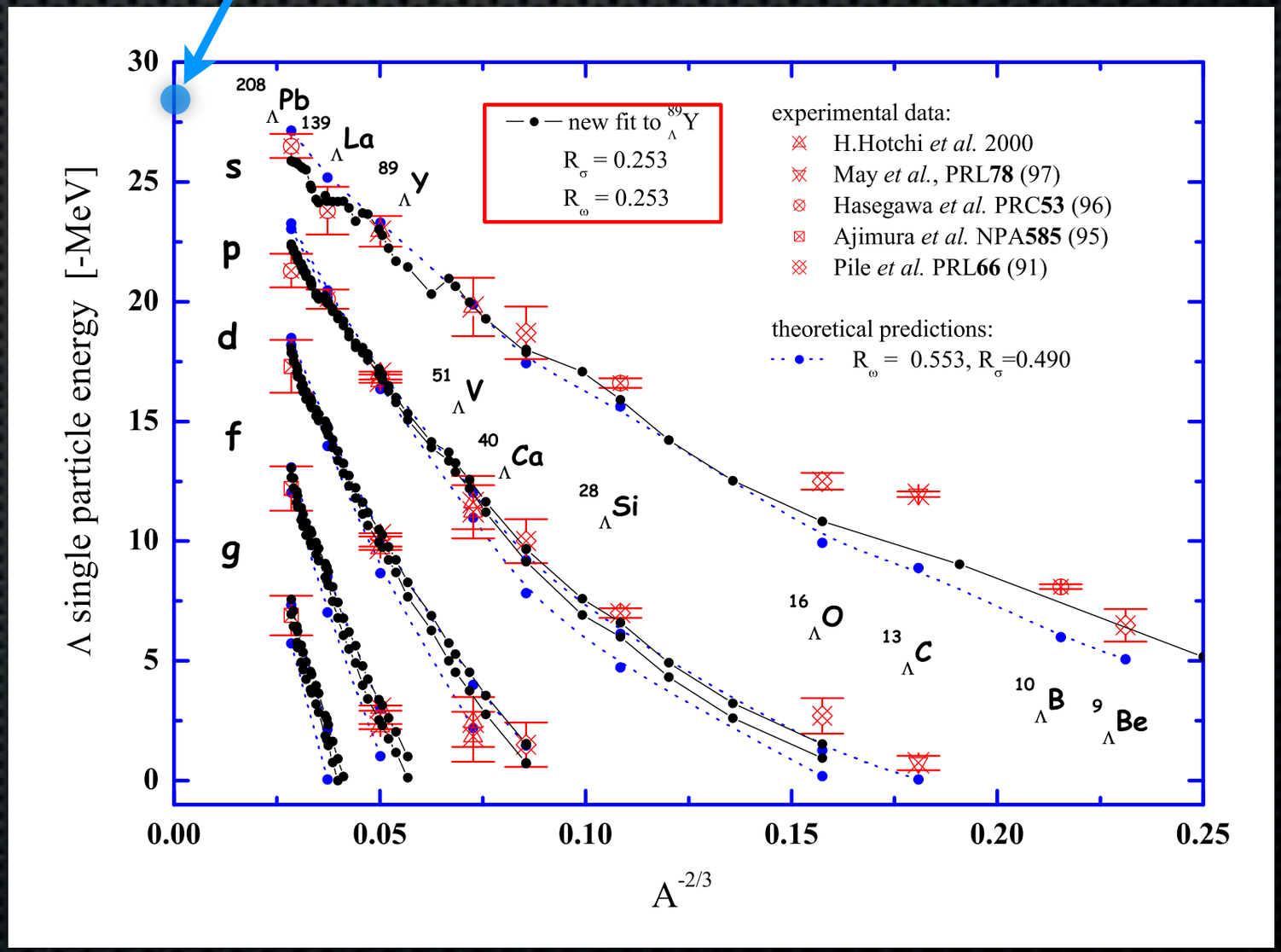
S=-1 Baryon Systems

Success of (π^+,K^+) Spectroscopy



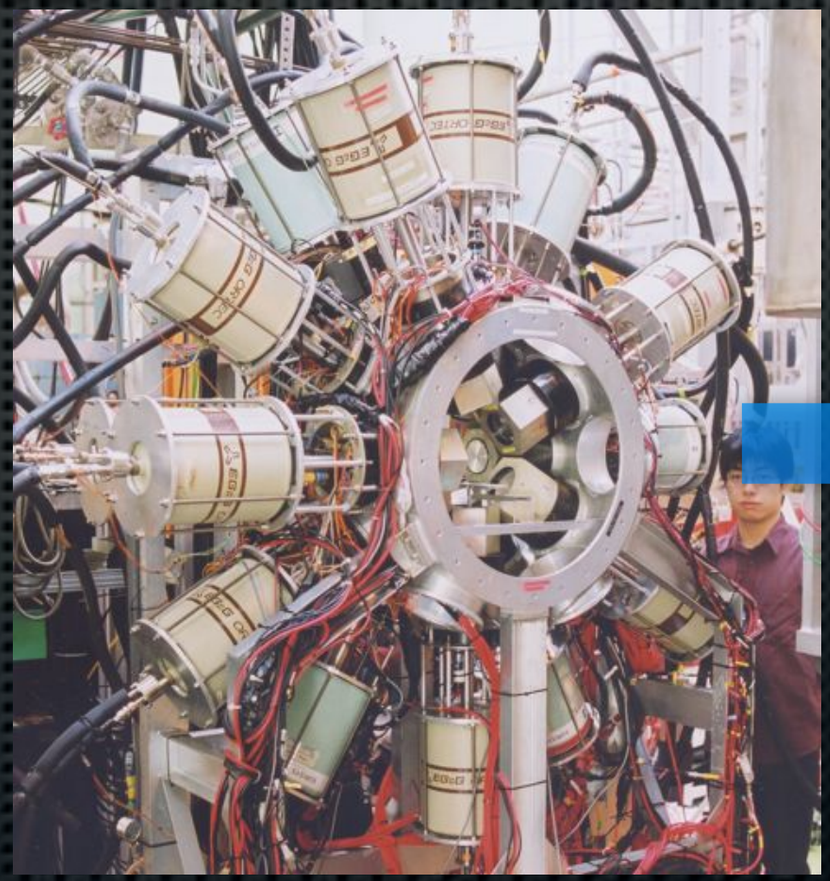
H.Hotchi et al., PRC 64, 044302(2001)

- Λ single-particle energy
  → U_Λ=28 MeV

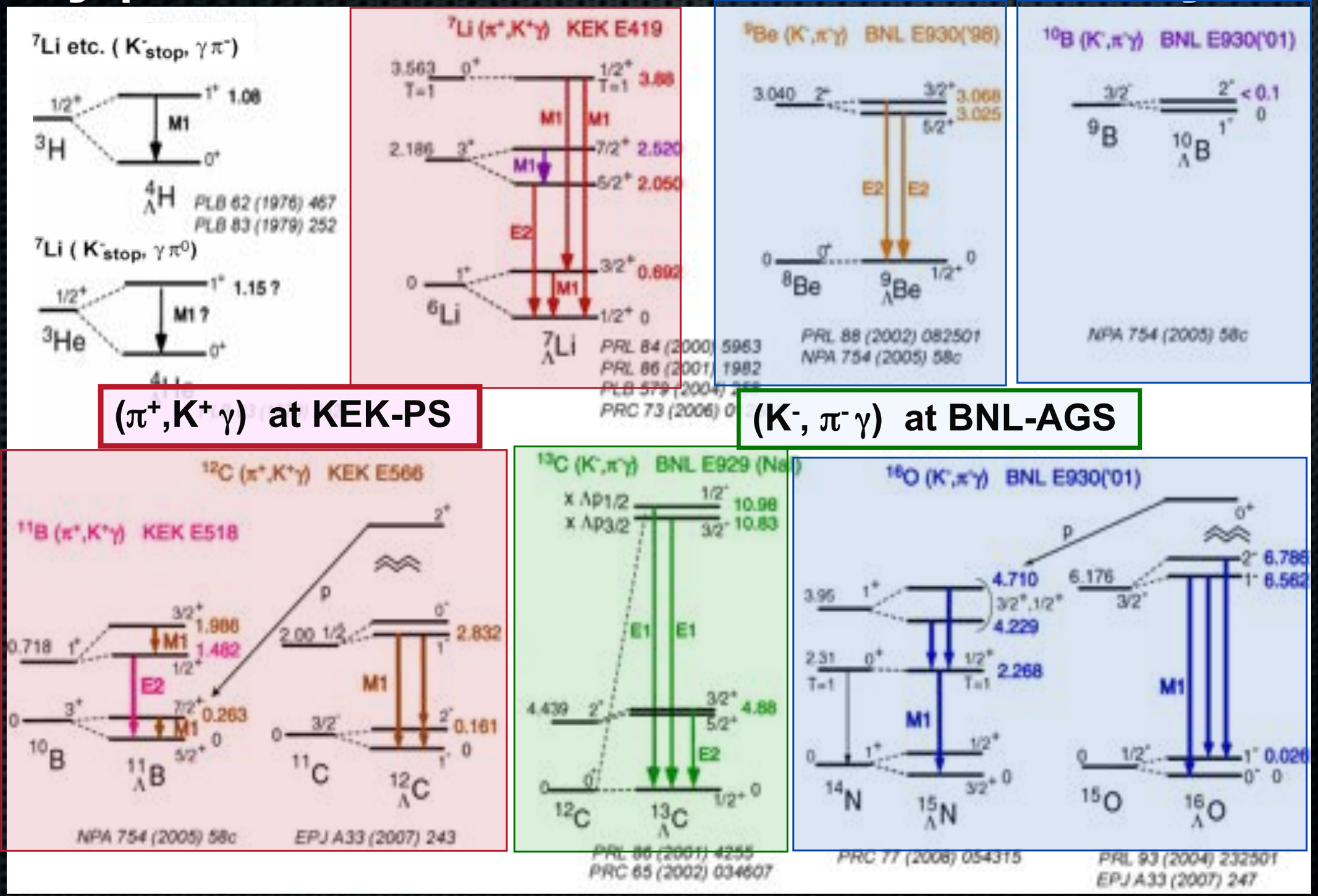


Success of Hypernuclear Gamma-Ray Spectroscopy

- Hyperball : Tohoku/KEK/Kyoto in 1998
  - 14 Ge(r.e.60%);
    Ω~15%, ε~3% at 1 MeV
  - BGO suppressor



Hypernuclear Gamma-rays



by H. Tamura

ΛN Effective Interaction

$$V_{\Lambda N}^{eff} = V_0(r) + V_\sigma(r)\vec{s_\Lambda}\vec{s_N} + V_\Lambda(r)\vec{\ell}_{\Lambda N}\vec{s_\Lambda} + V_N(r)\vec{\ell}_{\Lambda N}\vec{s_N} + V_T(r)S_{12}$$

Δ S_Λ S_N T

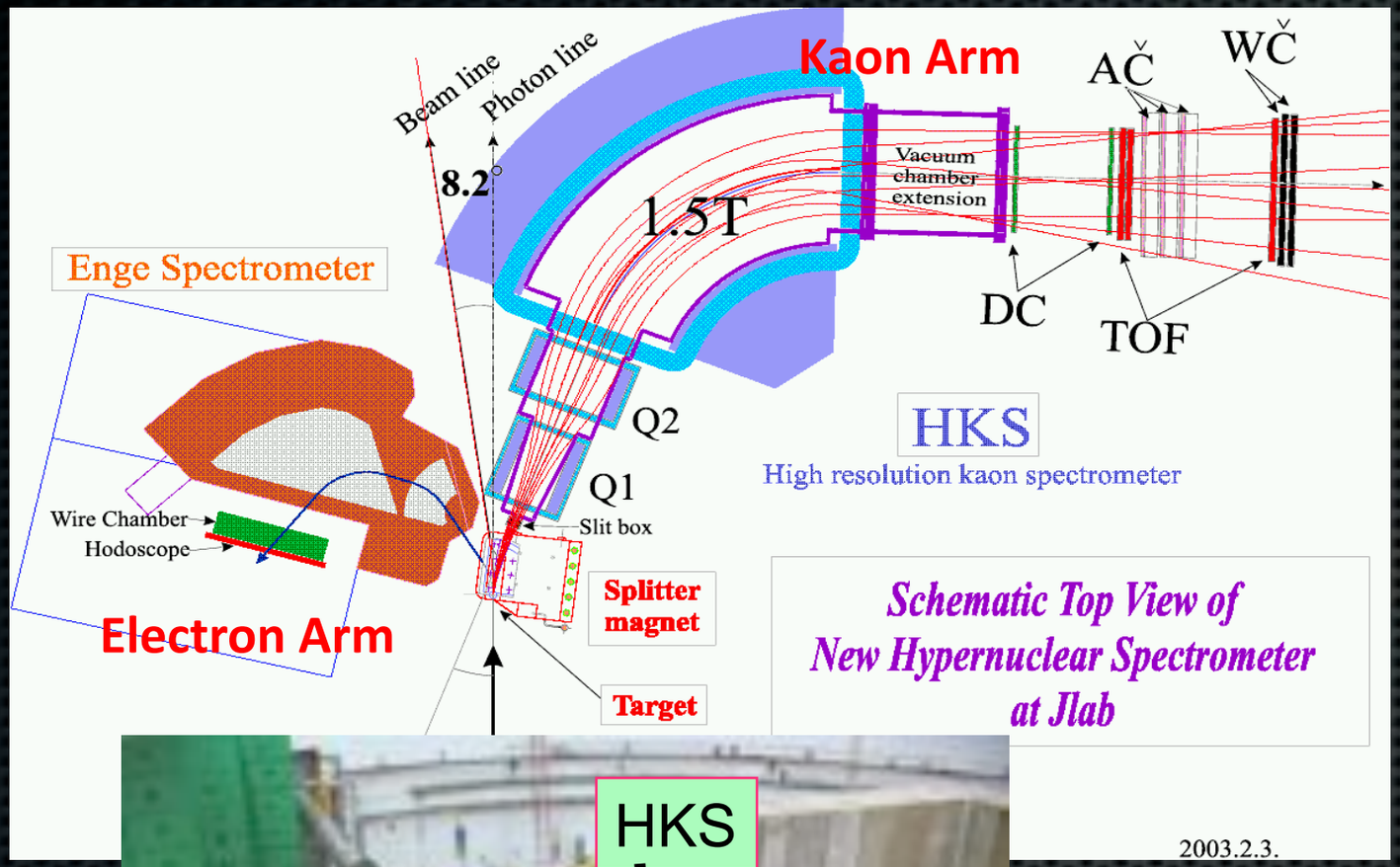
Parameters in MeV

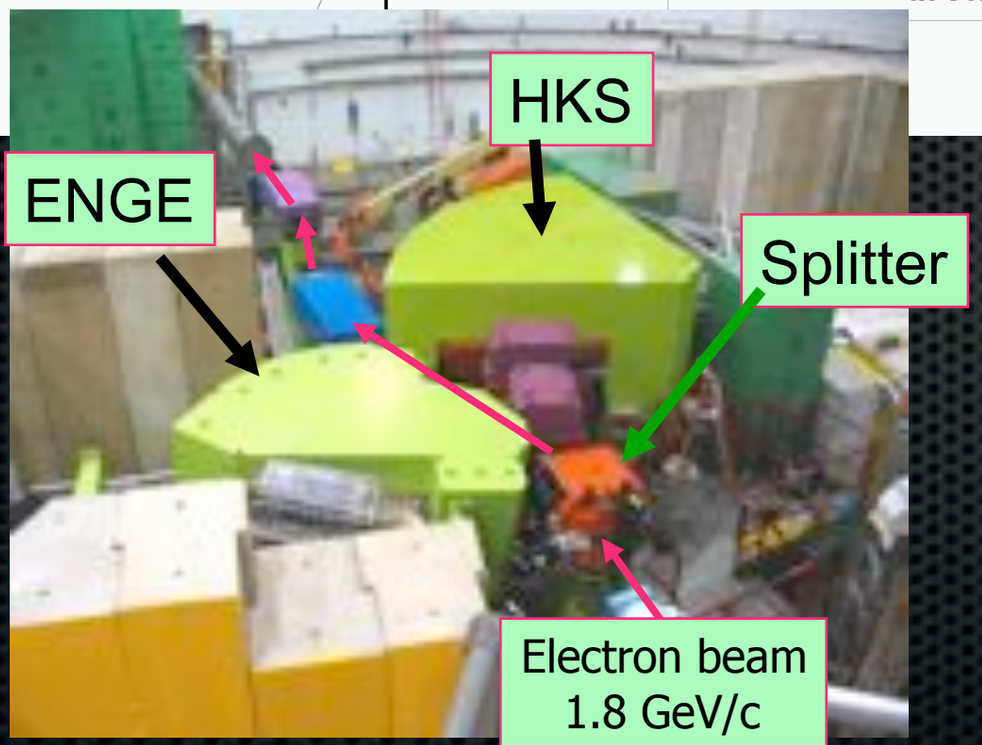
	Δ	S_Λ	S_N	T
$A = 7-$?	0.430	−0.015	−0.390	0.030
$A = 11 - 16$	0.330	−0.015	−0.350	0.024

Very small LS

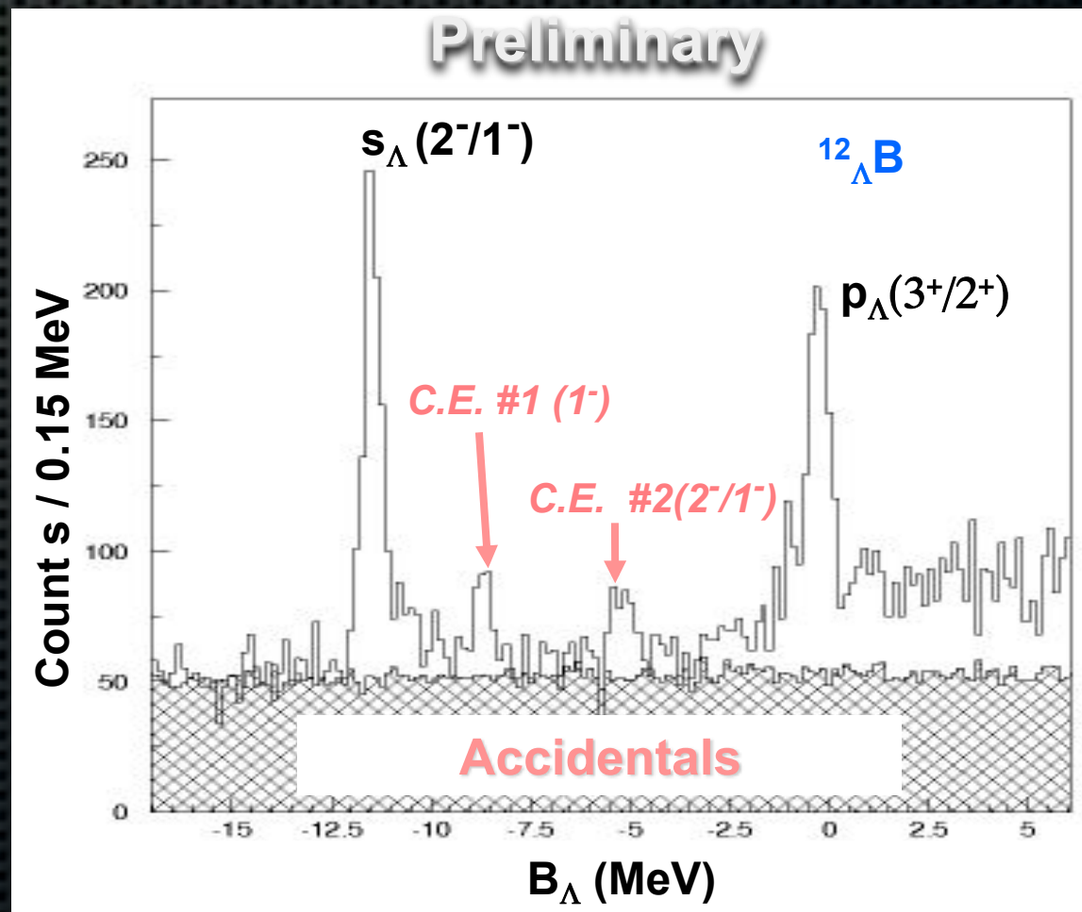
by D.J. Millener

JLab: (e,e'K$^+$) High-resolution Spectrometer in Hall-A & -C





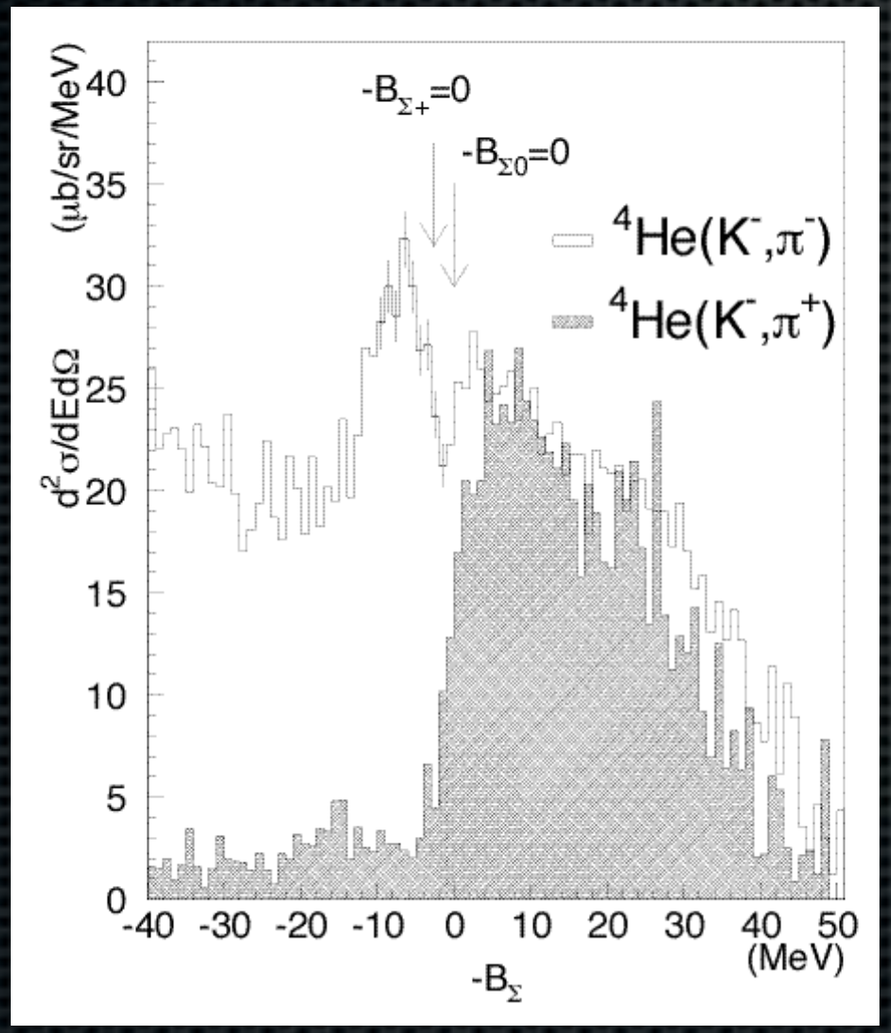
O. Hashimoto @ Hyp-X



- $^{12}_\Lambda$B Ground state resolution: 465 keV FWHM

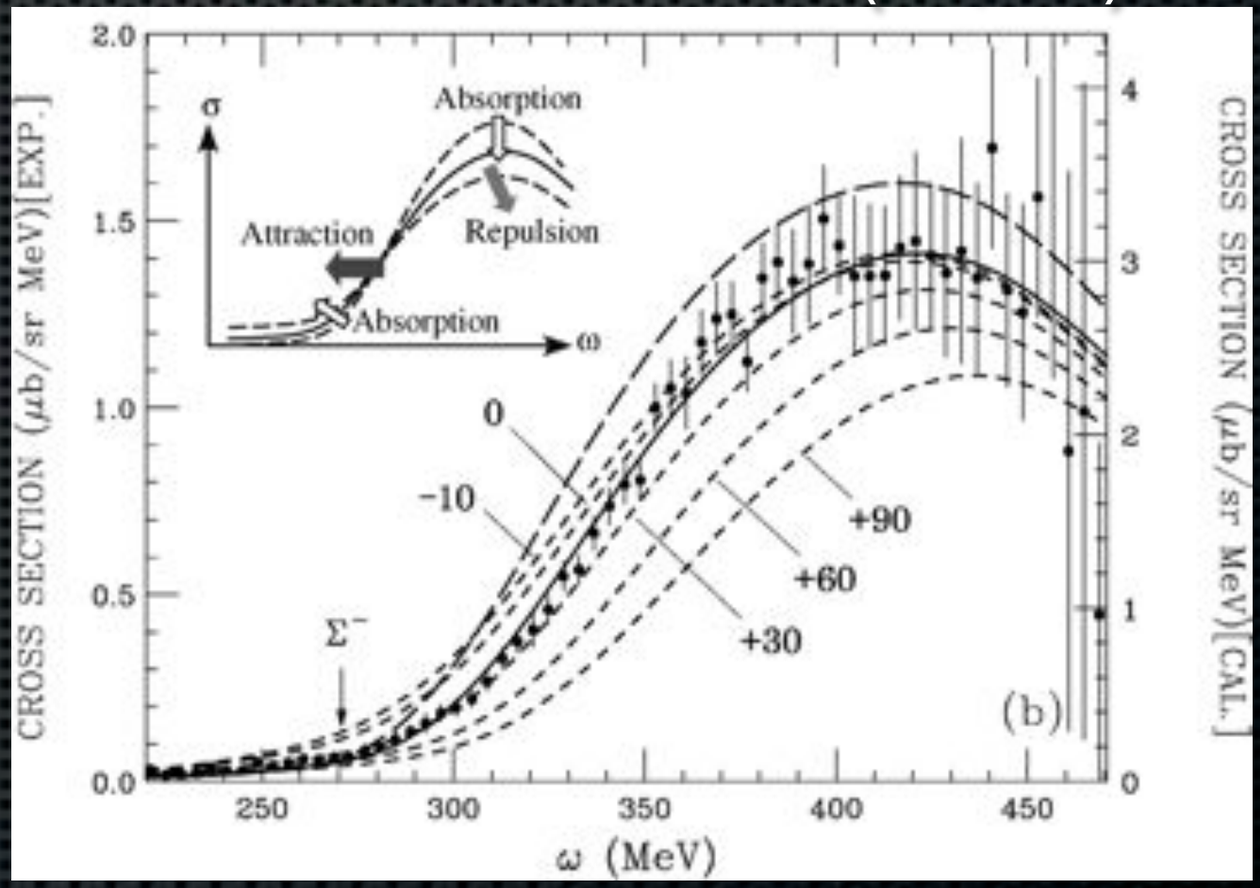
Σ -Hypernuclei

- One bound state observed: $^{4}_{\Sigma}$He



T. Nagae et al., PRL 80 (1998) 1605.

^{28}Si(π$^-$,K$^+$)



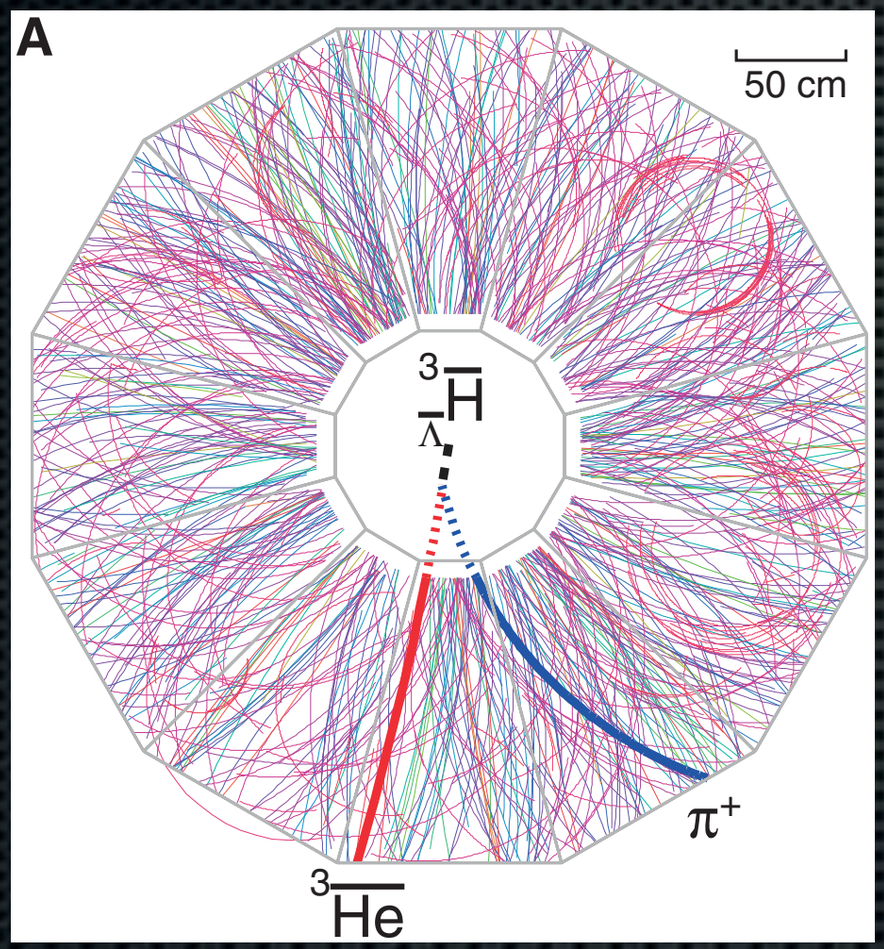
T. Harada and Y. Hirabayashi, NPA 759 (2005) 143.

Σ^--Nucleus potential: Repulsive

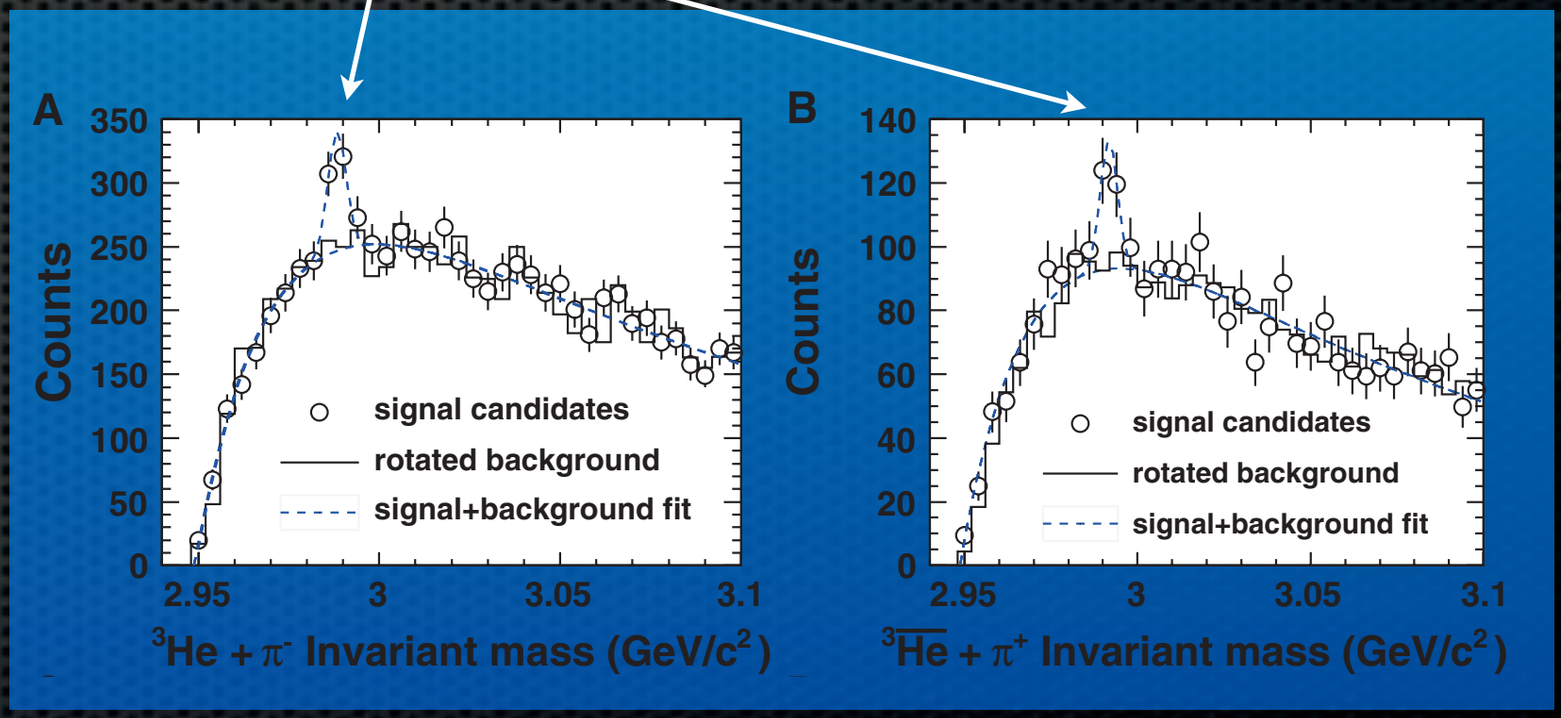
Observation of Anti-Hypernucleus at RHIC

The STAR Collaboration, Science 328 (2010) 58.

$$\overline{{}^{3}_{\Lambda}\mathrm{H}} \rightarrow \pi^{+} + \overline{{}^{3}\mathrm{He}}$$



$$\overline{{}^{3}_{\Lambda}\mathrm{H}}/{}^{3}_{\Lambda}\mathrm{H} = 0.49 \pm 0.18 \pm 0.07$$



Life time($^{3}_{\Lambda}$H)=182+89/-45±27 ps

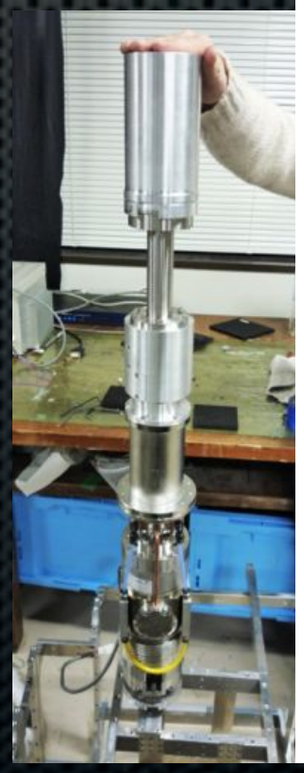
Gamma-ray Spectroscopy of Light Hypernuclei

J-PARC E13
H. Tamura et al.

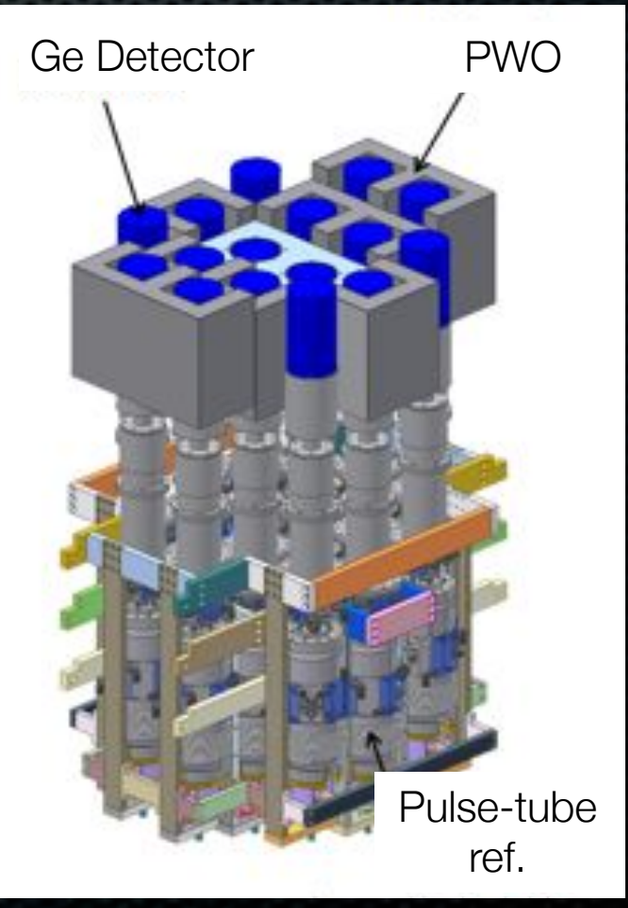
- Spin-flip B(M1) measurement for g_Λ in nuclei
  - ^{7}Li($K^-,\pi^-\gamma$)$^{7}_{\Lambda}$Li at 1.5 GeV/c: M1($3/2^+ \rightarrow 1/2^+$)

Hyperball-J

- ΛN interaction in sd-shell hypernuclei
  - $^{19}_{\Lambda}$F: easiest in sd-shell
- ΛN interaction in p-shell hypernuclei
  - $^{10}_{\Lambda}$B
- etc.



Ge x32; ε~5.8% at 1 MeV
→ γ-γ coincidence



Neutron-rich Hypernuclei with (π^-,K^+) reaction

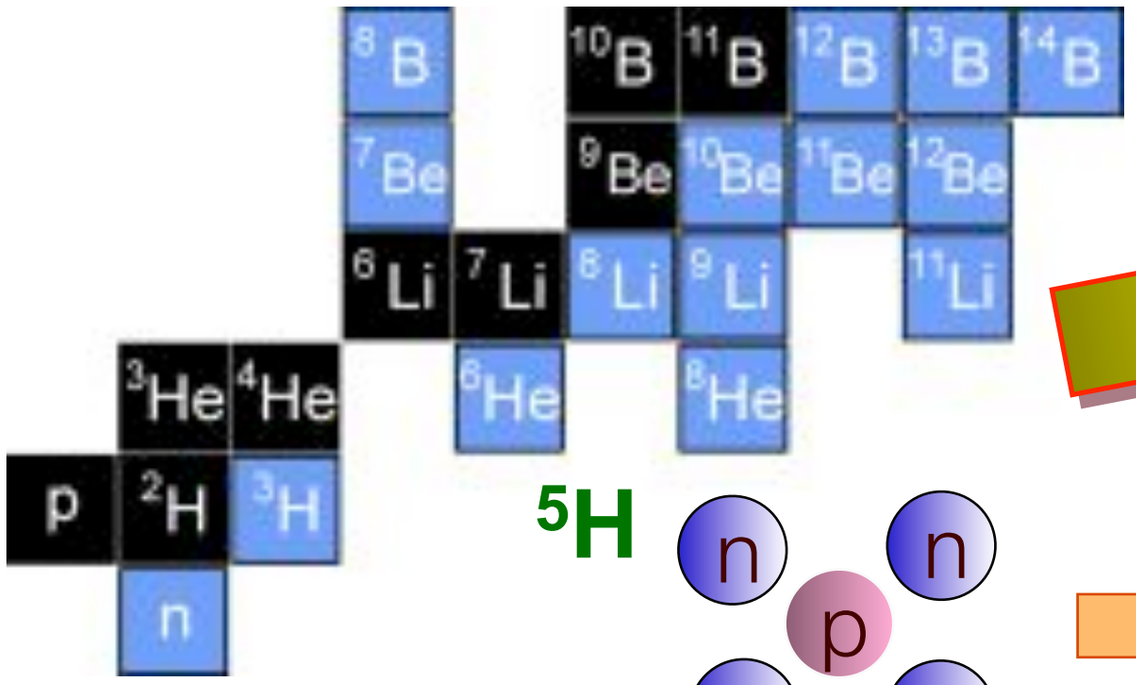
J-PARC E10
A. Sakaguchi et al.

NCX: (K^-,π^-), (π^+,K^+) reaction

SCX: $(e,e'K^+)$, (K^-,π^0), (π^-,K^0) reaction

DCX: (K^-,π^+), (π^-,K^+) reaction

ordinary nuclei



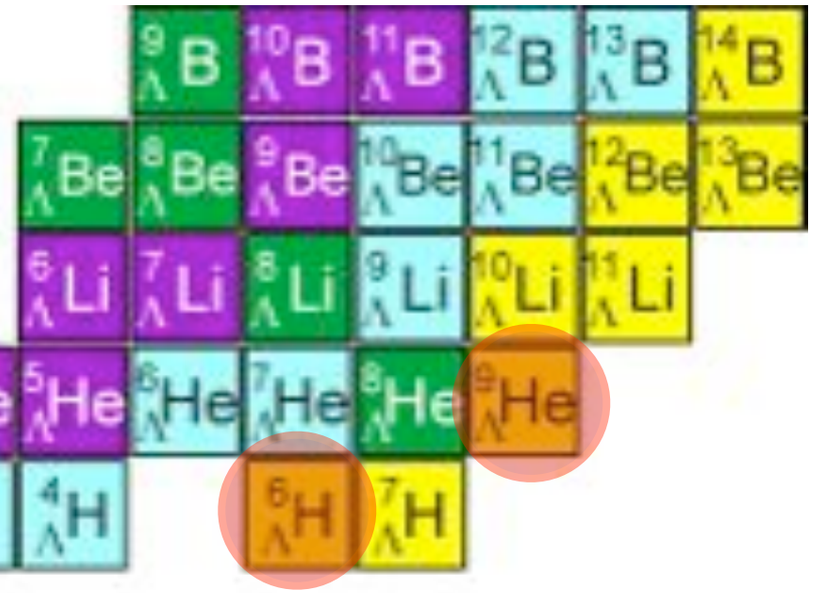
NCX

SCX

DCX

Λ

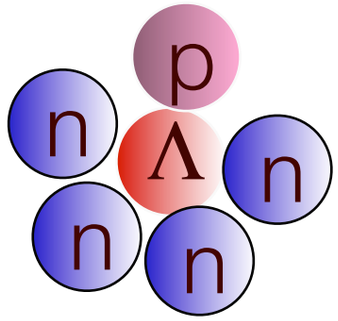
Λ-hypernuclei



^{5}H

unbound

$^{6}_{\Lambda}$H



Akaishi:
Glue-like role of Λ
(B_Λ=4.4 MeV)
+
ΛNN coherent coupling (+1.4 MeV)

"Hyperheavy hydrogen": deeply bound

S=-2 Baryon Systems

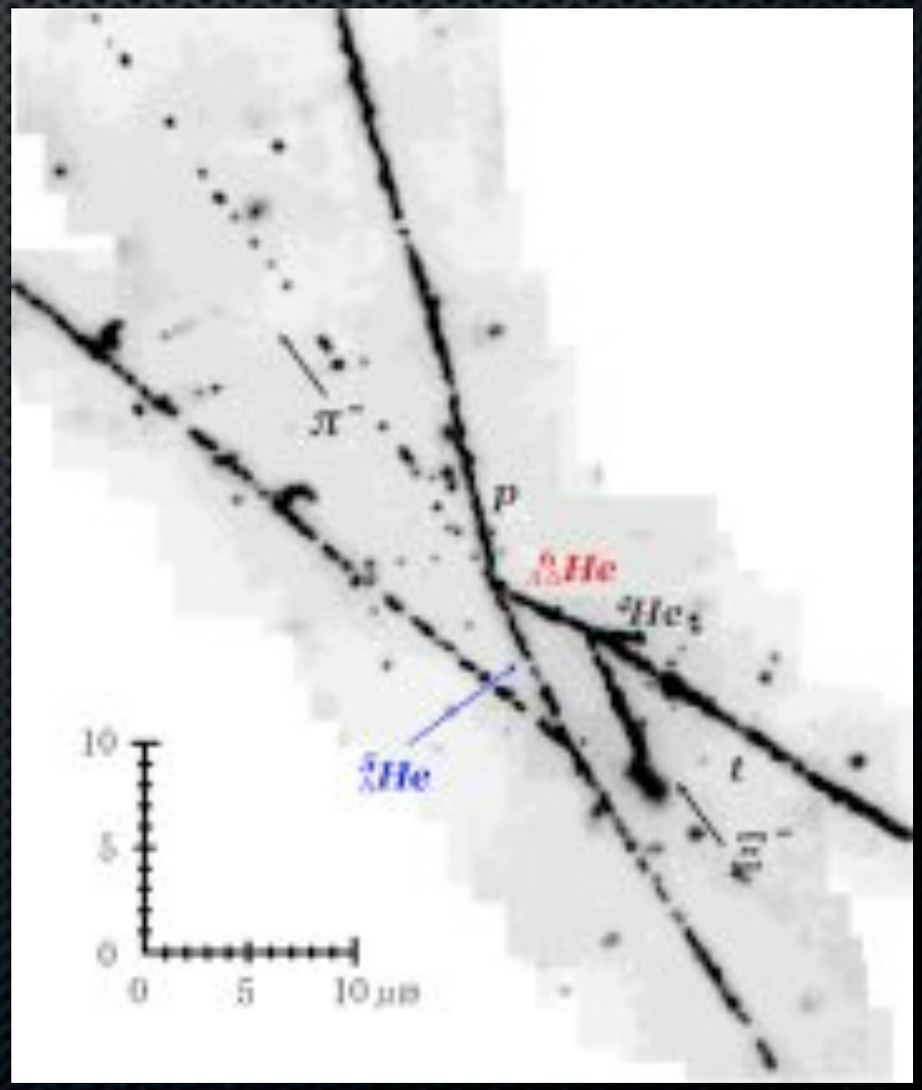
Double-Λ Hypernuclei

- "Nagara" event; ${}^{\Lambda\Lambda}{}^{6}\mathrm{He}$
  - Uniquely identified
  - $\Delta B_{\Lambda\Lambda}$=1.01±0.02+0.18/-0.11 MeV

0.67±0.17 MeV
(updated by Nakazawa@Hyp-X)

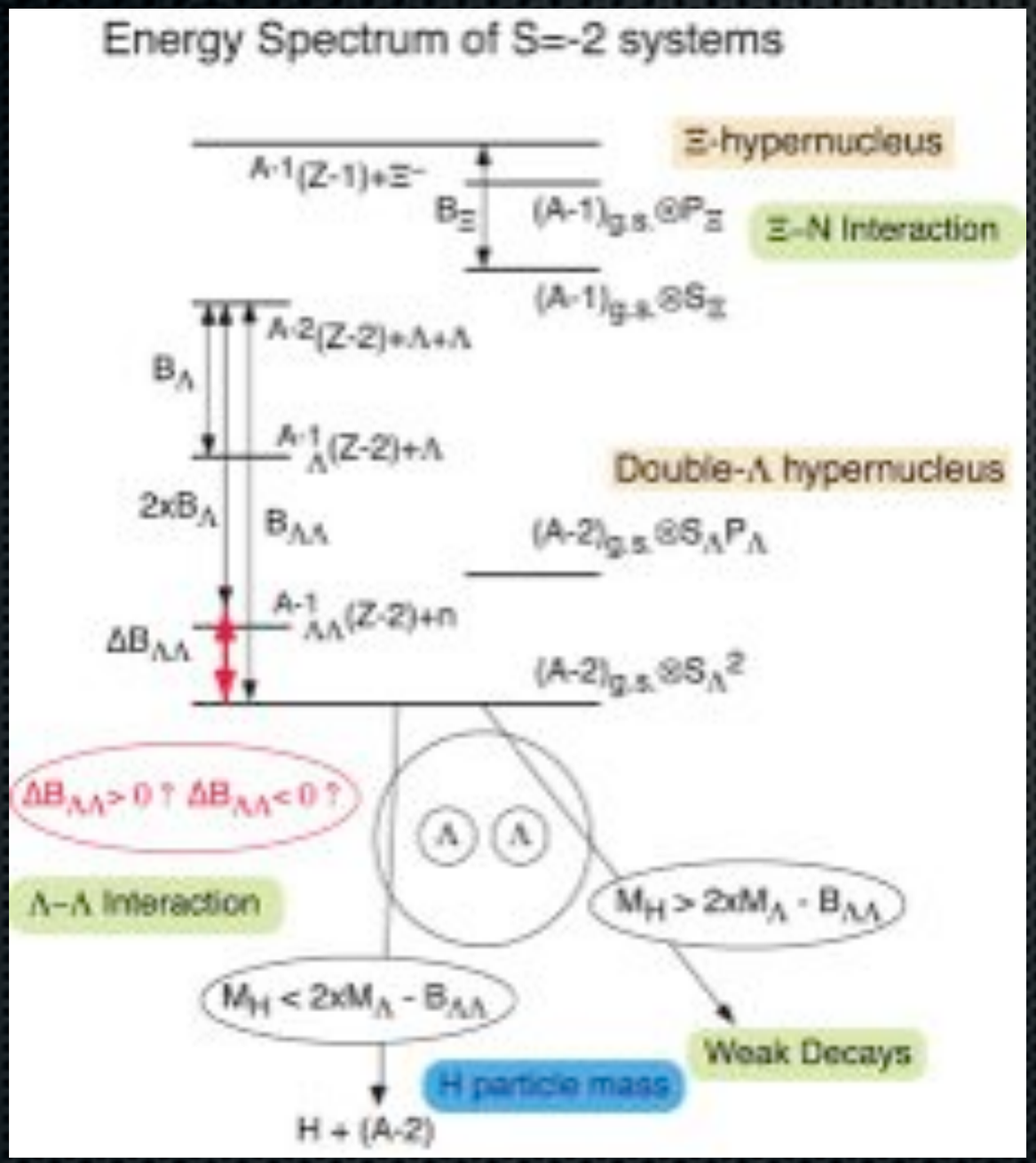
  - smaller than before (~4 MeV)

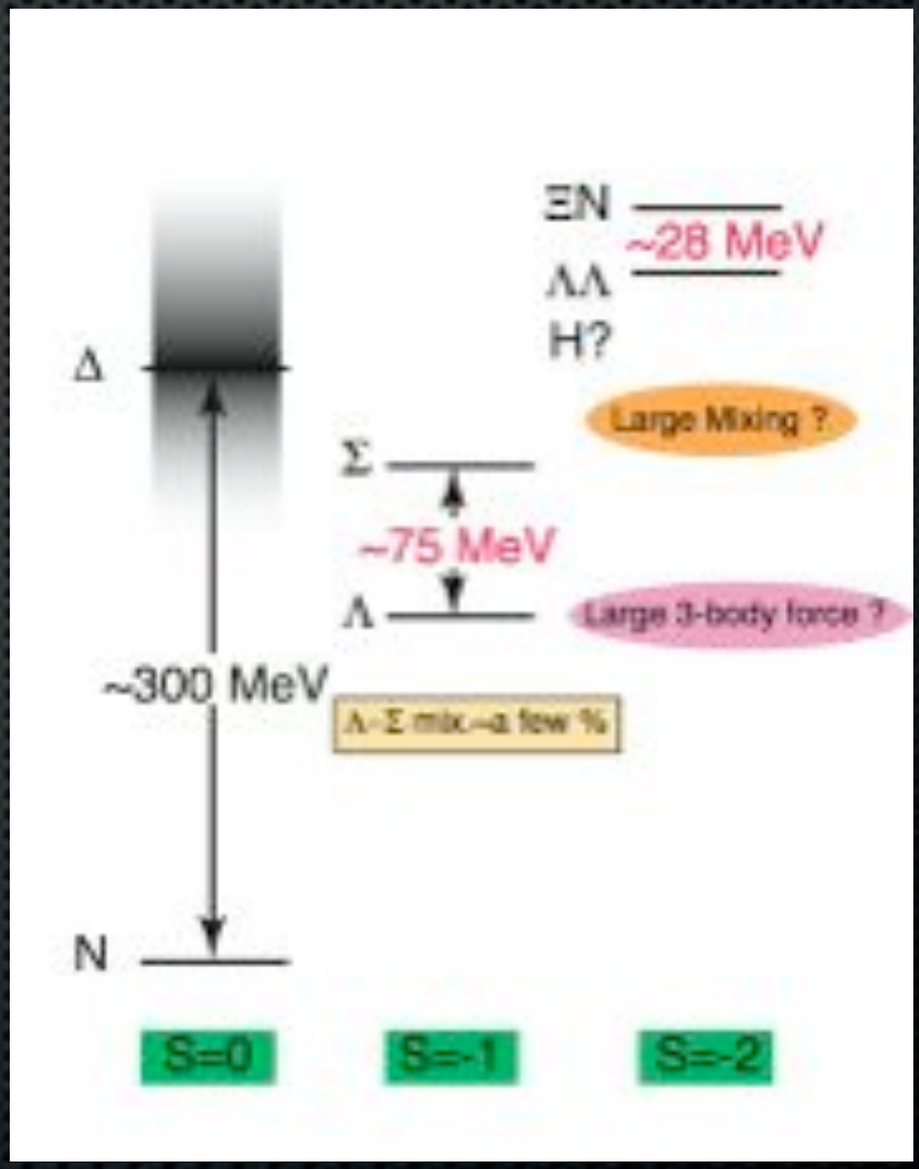
KEK E373



H. Takahashi et al., PRL87, (2001) 212502.

S=-2 World


Energy Spectrum of S=-2 systems
Ξ-hypernucleus
A-1(Z-1)+Ξ-
BΞ
(A-1)g.s.⊗PΞ
(A-1)g.s.⊗SΞ
Ξ-N Interaction
A-2(Z-2)+Λ+Λ
BΛ
A-1Λ(Z-2)+Λ
Double-Λ hypernucleus
2xBΛ
BΛΛ
(A-2)g.s.⊗SΛPΛ
A-1ΛΛ(Z-2)+n
ΔBΛΛ
(A-2)g.s.⊗SΛ2
ΔBΛΛ> 0 ? ΔBΛΛ< 0 ?
Λ Λ
Λ-Λ Interaction
MH > 2xMΛ - BΛΛ
MH < 2xMΛ - BΛΛ
Weak Decays
H particle mass
H + (A-2)

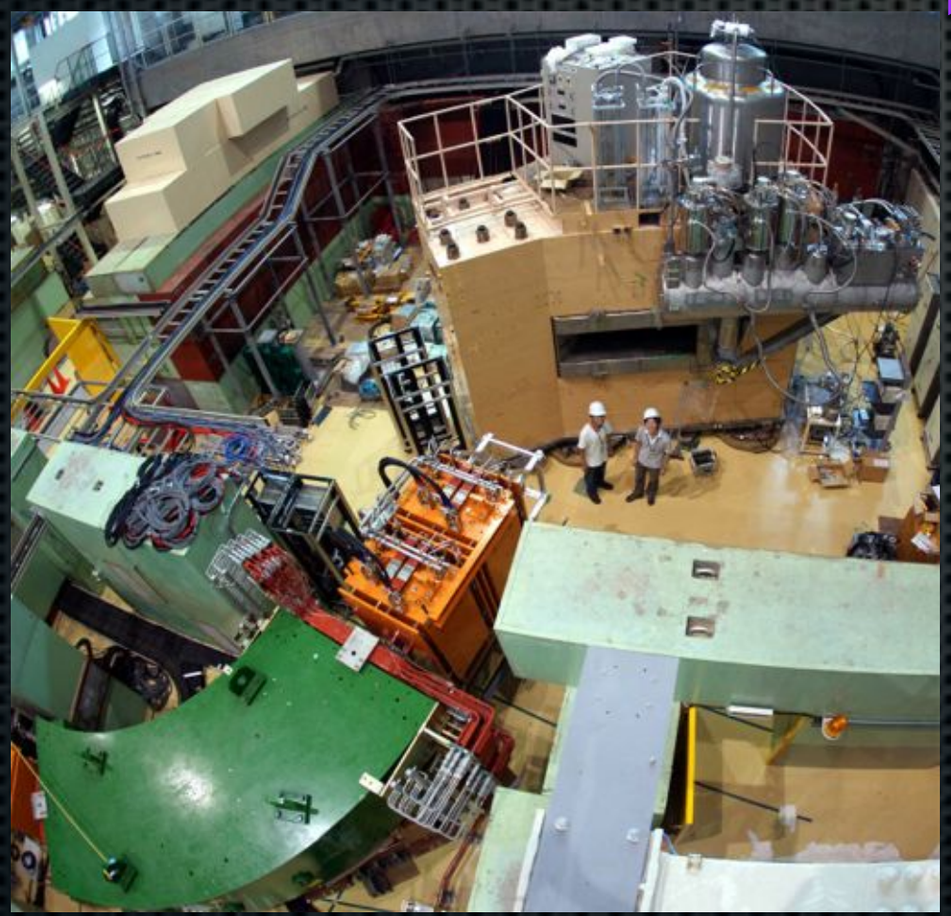

ΞN
~28 MeV
ΛΛ
H?
Large Mixing ?
Δ
Σ
~75 MeV
Λ
Large 3-body force ?
~300 MeV
Λ-Σ mix.~a few %
N
S=0
S=-1
S=-2

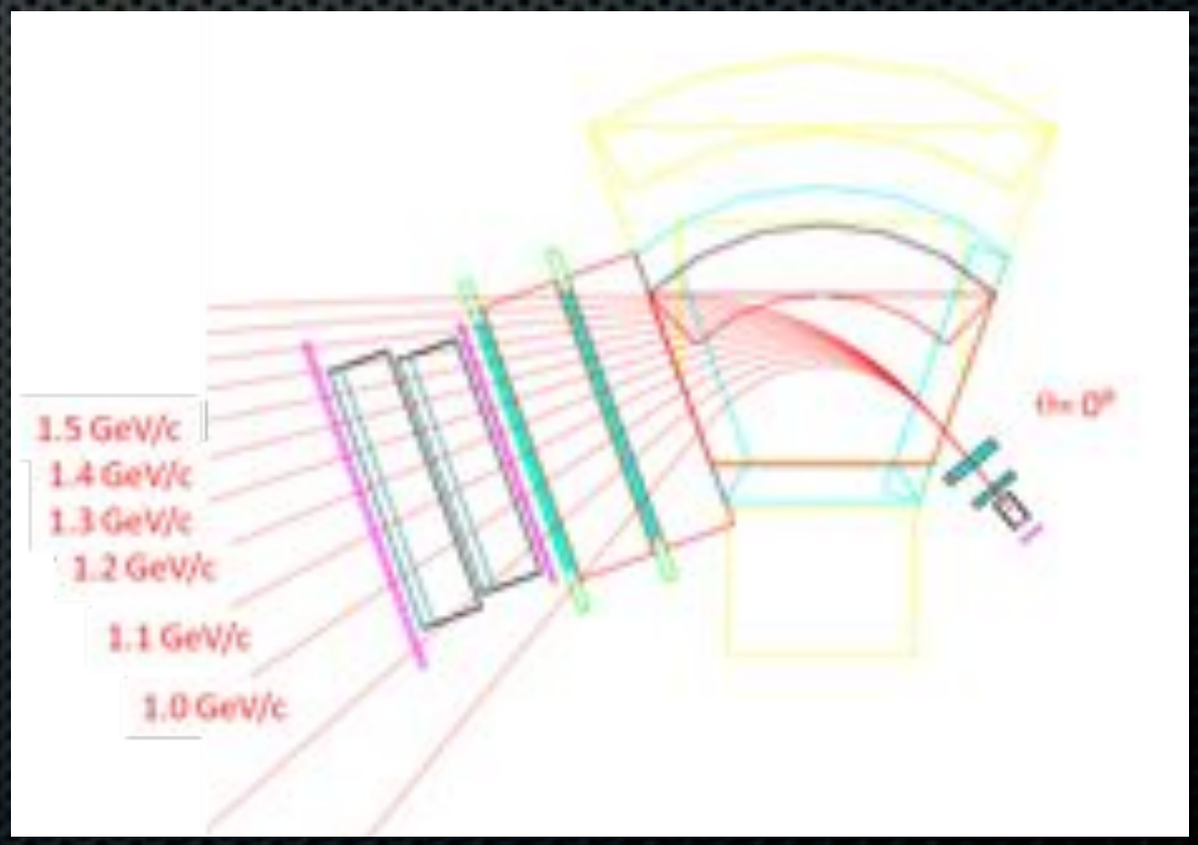
Spectroscopic Study of Ξ-Hypernucleus, $^{12}_{\Xi}$Be, via the ^{12}C(K^-,K^+) Reaction

J-PARC E05
T. Nagae et al.

- Discovery of Ξ-hypernuclei
- Measurement of Ξ-nucleus potential depth and width

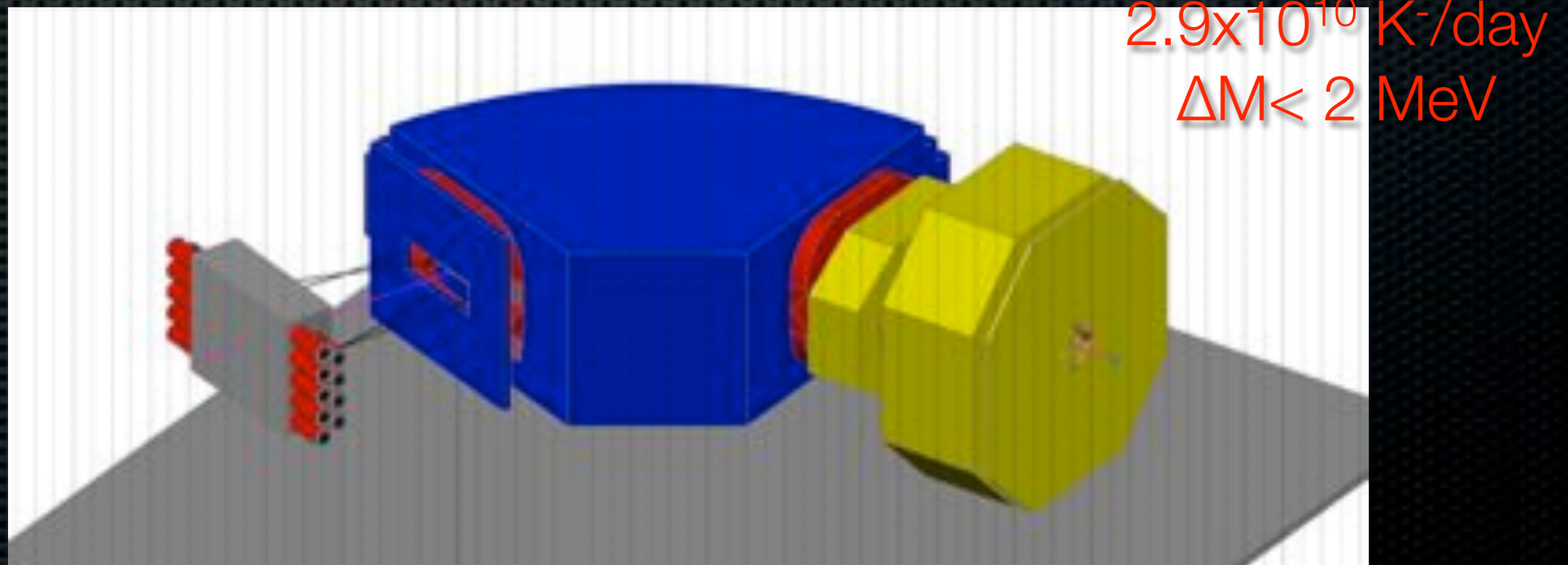
of $^{12}_{\Xi}$Be S=-1 → S=-2 (Multi-Strangeness System)





E05 Phase 2 with S-2S

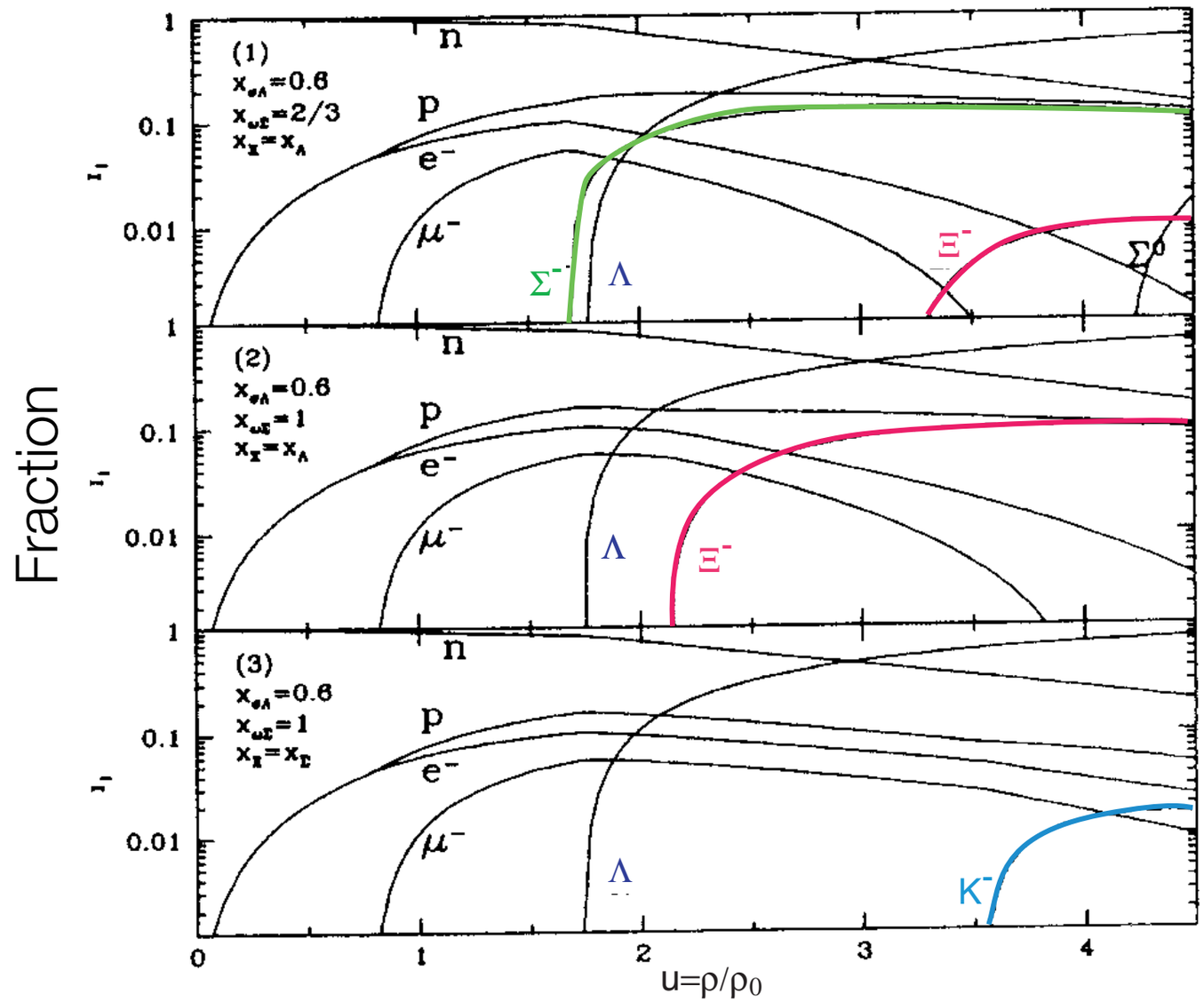
- Grant-In-Aid for Specially promoted research: 2011 – 2015
- 60 msr, Δp/p=0.05% → ΔM=1.5 MeV
- Construction of S-2S(QQD): ~3 years
  - Installation in 2014
- Data taking in 2015 with > 150 kW !!



Ξ-Nucleus potential ?

- Chemical Potential:

$$\mu_B = m_B + \frac{{k_F}^2}{2m_B} + U(k_F)$$



U Σ <0, U Ξ <0

U Σ >0, U Ξ <0

U Σ >0, U Ξ >0

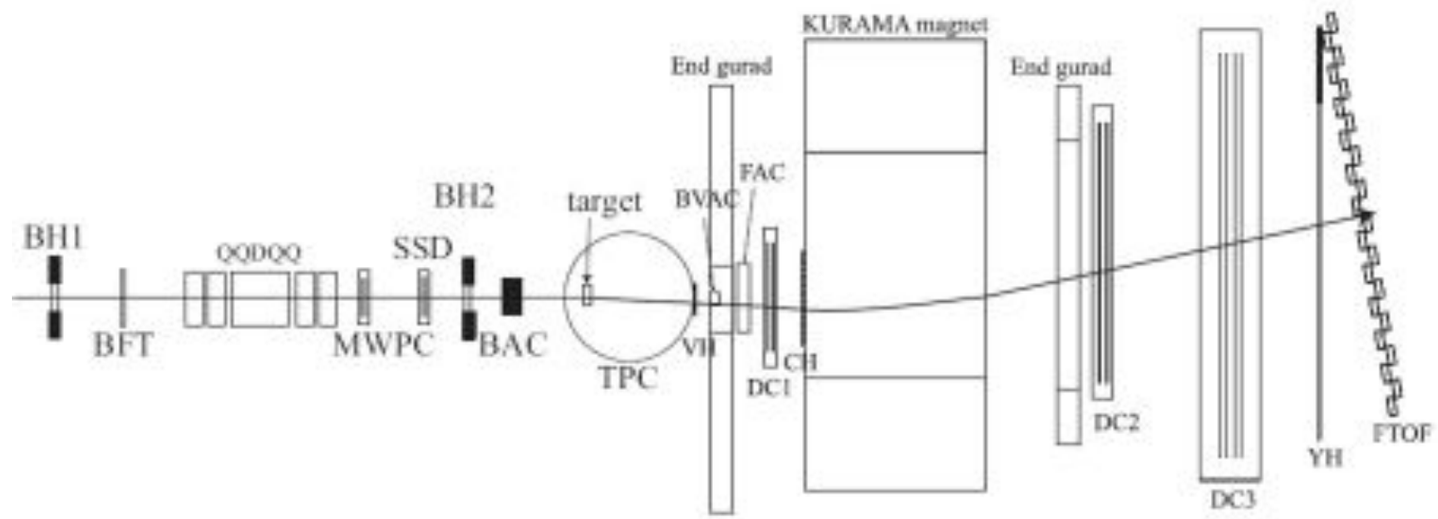
H search at J-PARC

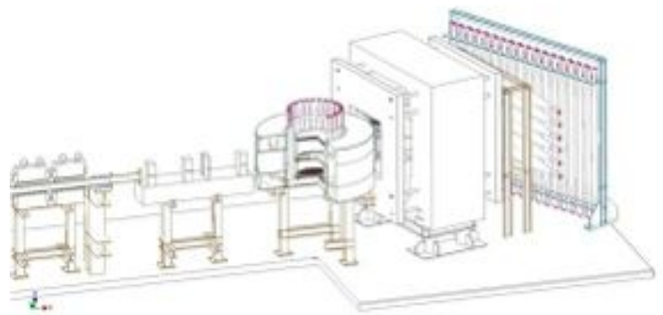
P42

by J.K. Ahn & K. Imai et al.

- (K^-,K^+) reaction

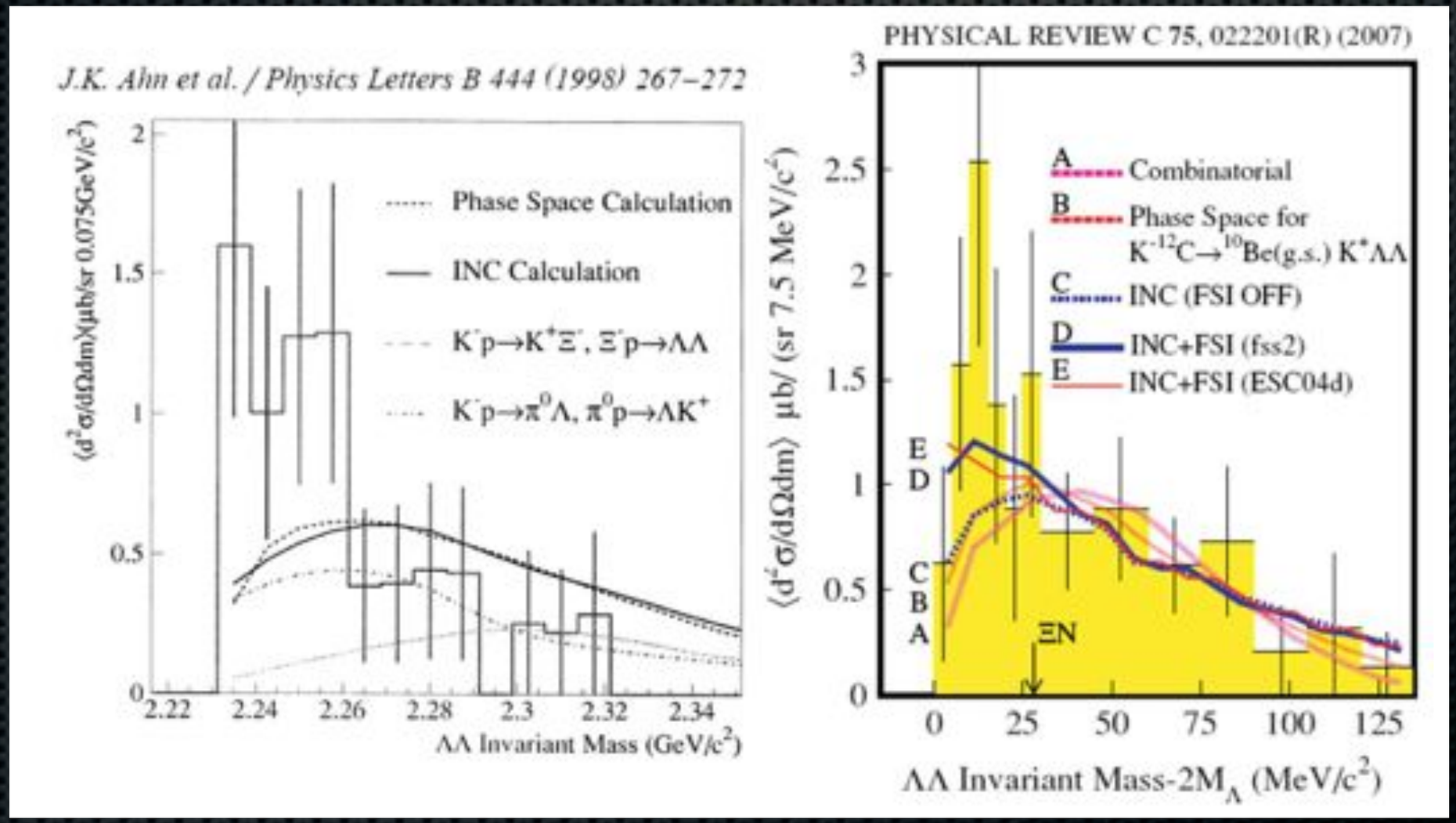
- Hyperon Spectrometer + K^+ Spectrometer





ΛΛ invariant-mass spectra

- H resonance ? ; KEK E224 & E522



$S = -2, -3, -4$

$\mathcal{S} = -2, -3, -4$ **deuteron-like** $L = 0$ **dibaryon candidates**

	$\Sigma\Sigma$ $(I = 2, {}^1S_0)$	$\Lambda\Xi$ $(I = \frac{1}{2}, {}^1S_0)$	$\Sigma\Xi$ $(I = \frac{3}{2}, {}^1S_0)$	$\Sigma\Xi$ $(I = \frac{3}{2}, {}^3S_1)$	$\Xi\Xi$ $(I = 1, {}^1S_0)$
fss2	$-$	$-$	$-$	$-$	$-$
NSC97	$+$	$-$	$+$	$+$	$+$
EFT (LO)	$-$	$+$	$+$	$-$	$+$

fss2: Y. Fujiwara, Y. Suzuki, C. Nakamoto, Prog. Part. Nucl. Phys. **58** (2007) 439

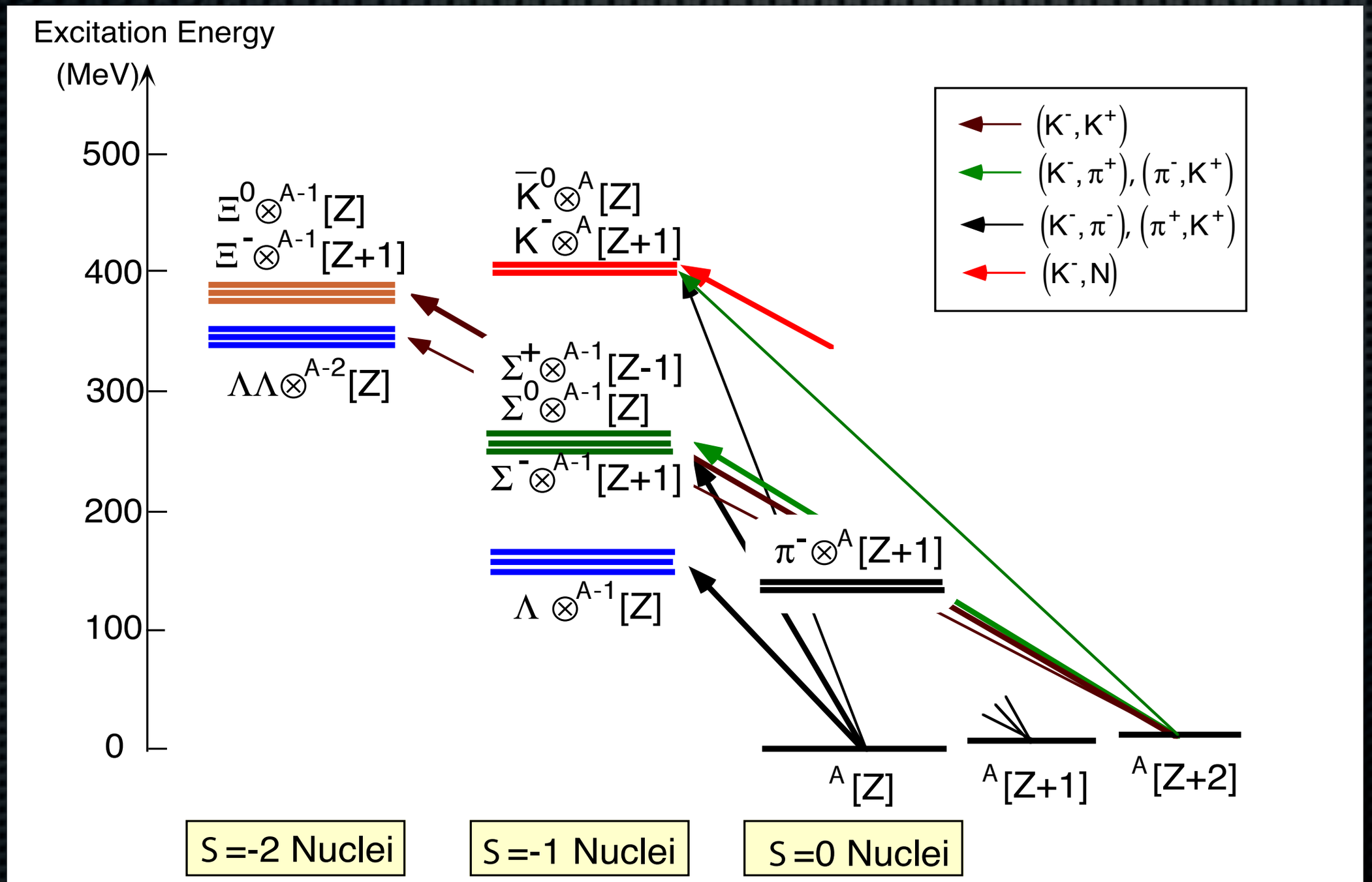
NSC97: V.G.J. Stoks, T.A. Rijken, Phys. Rev. C **59** (1999) 3009

EFT (LO): J. Haidenbauer, U.-G. Meißner, Phys. Lett. B **684** (2010) 275

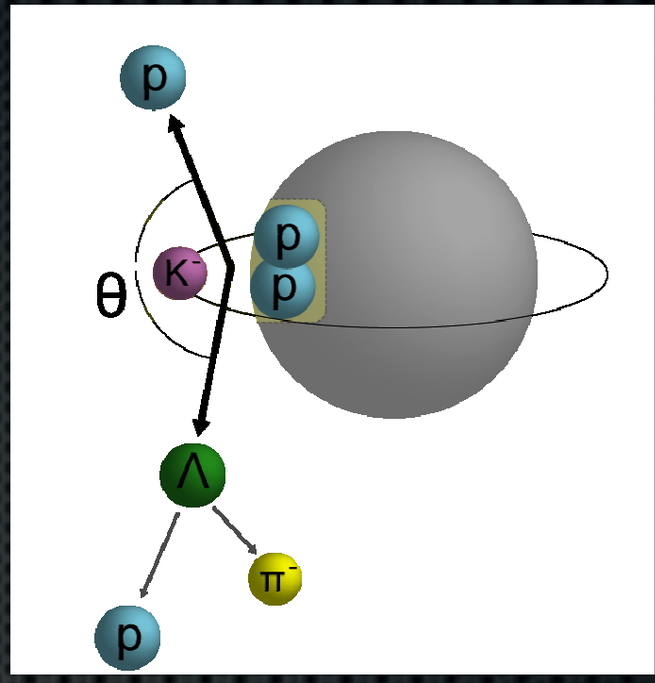
By A. Gal

Kaonic Nuclei

Meson-Bayon Bound Systems with Strangeness



New FINUDA data on K^-pp



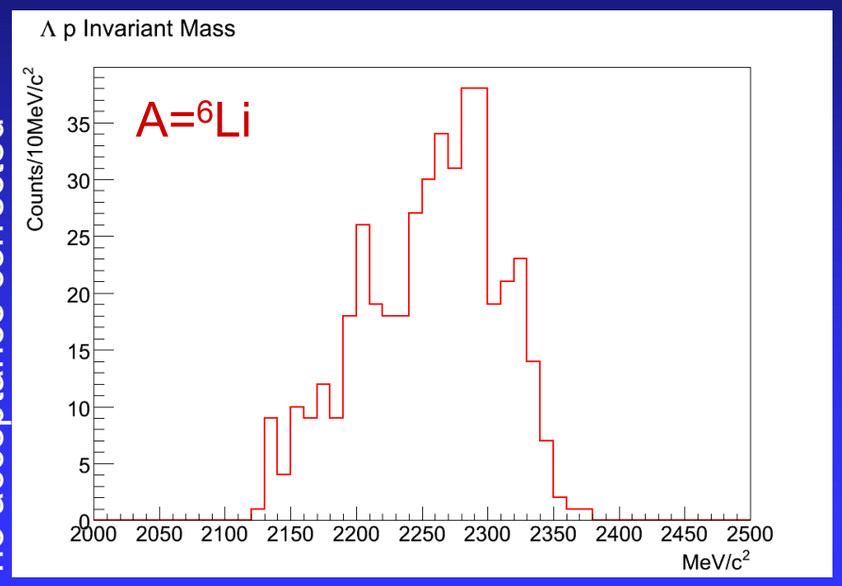
- First evidence of K^-pp with $^6Li+^7Li+^{12}C$

  B=115+6/-5+3/-4 MeV
  Γ= 67+14/-11+2/-3 MeV

M. Agnello et al., PRL94, (2005) 212303

- Confirmed for ^6Li only, with better statistics

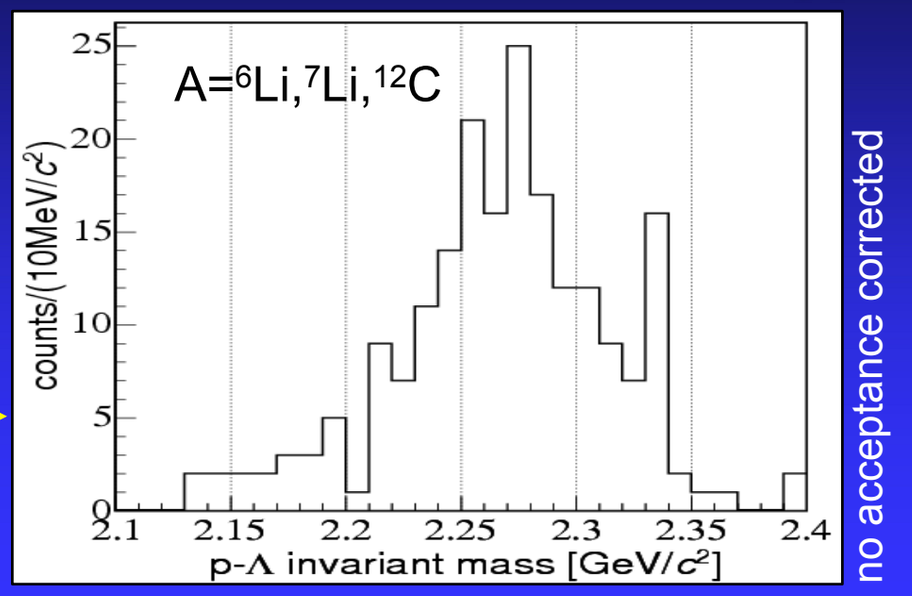
S. Piano@Hyp-X



New
inv mass spectra
compatible with
published one

New data ⟷ Old data

Same cuts applied



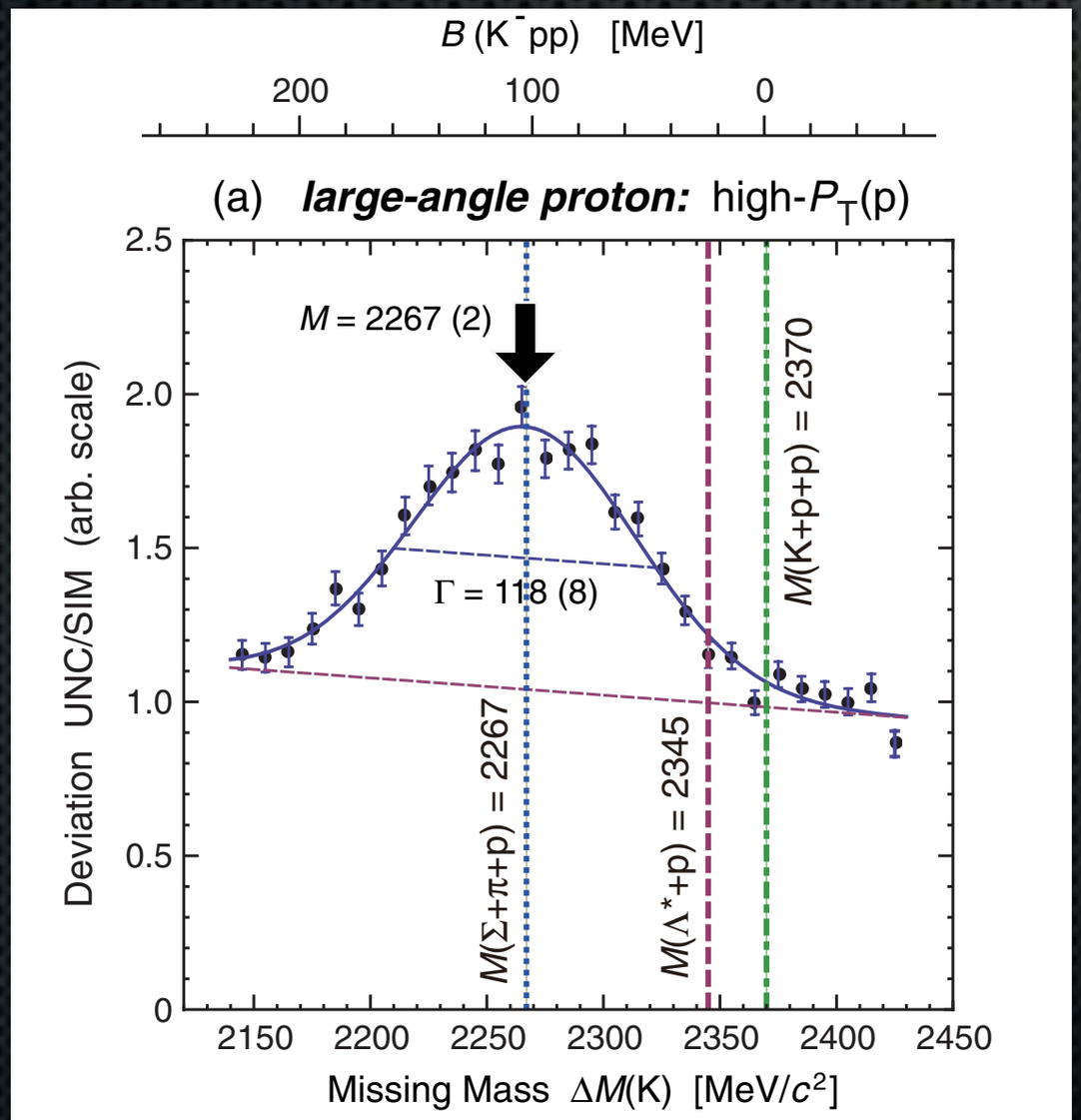
FINUDA Coll., PRL 94(2005)212303

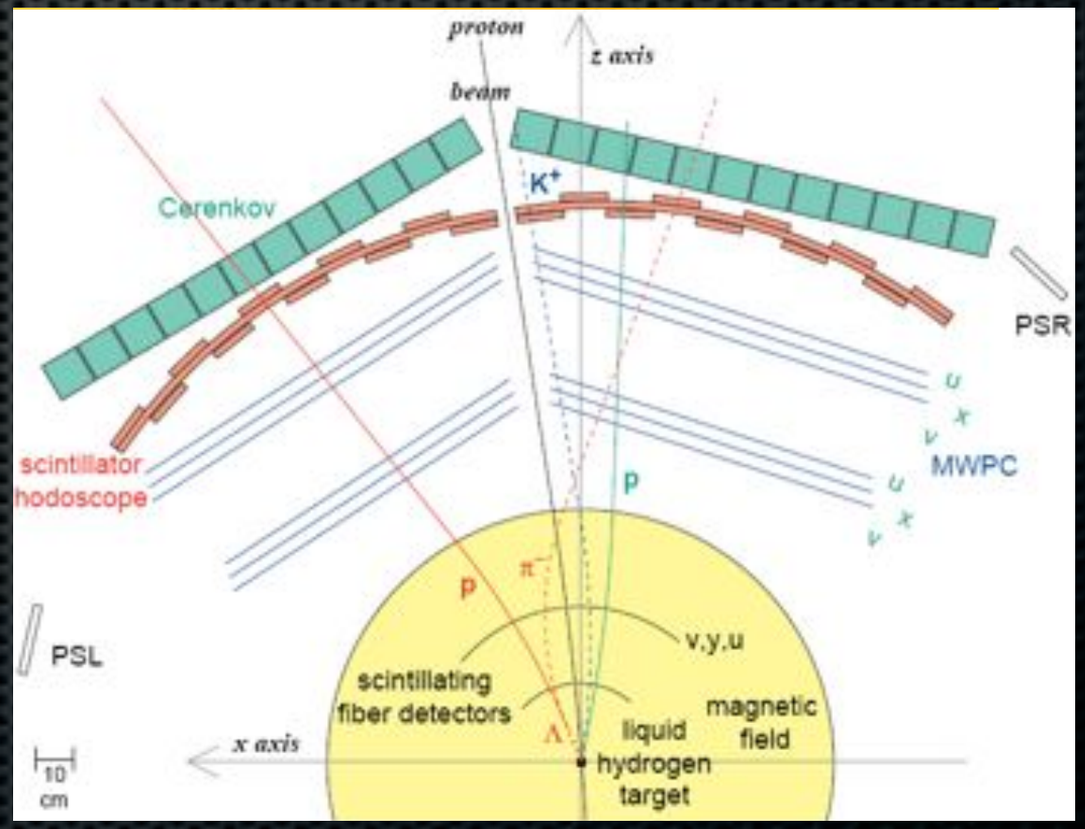
FSI, ΣN→ΛN conversion cannot explain the new data

DISTO data on K^-pp

- p+p→K^-pp + K^+ at 2.85 GeV
  - M=2267±3±5 MeV/c^2
  - Γ= 118±8±10 MeV

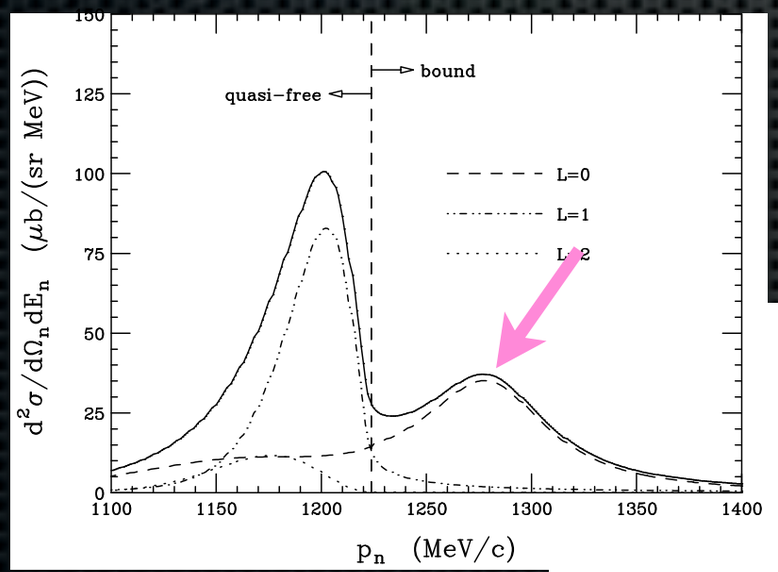
T. Yamazaki et al., PRL 104 (2010) 132502.



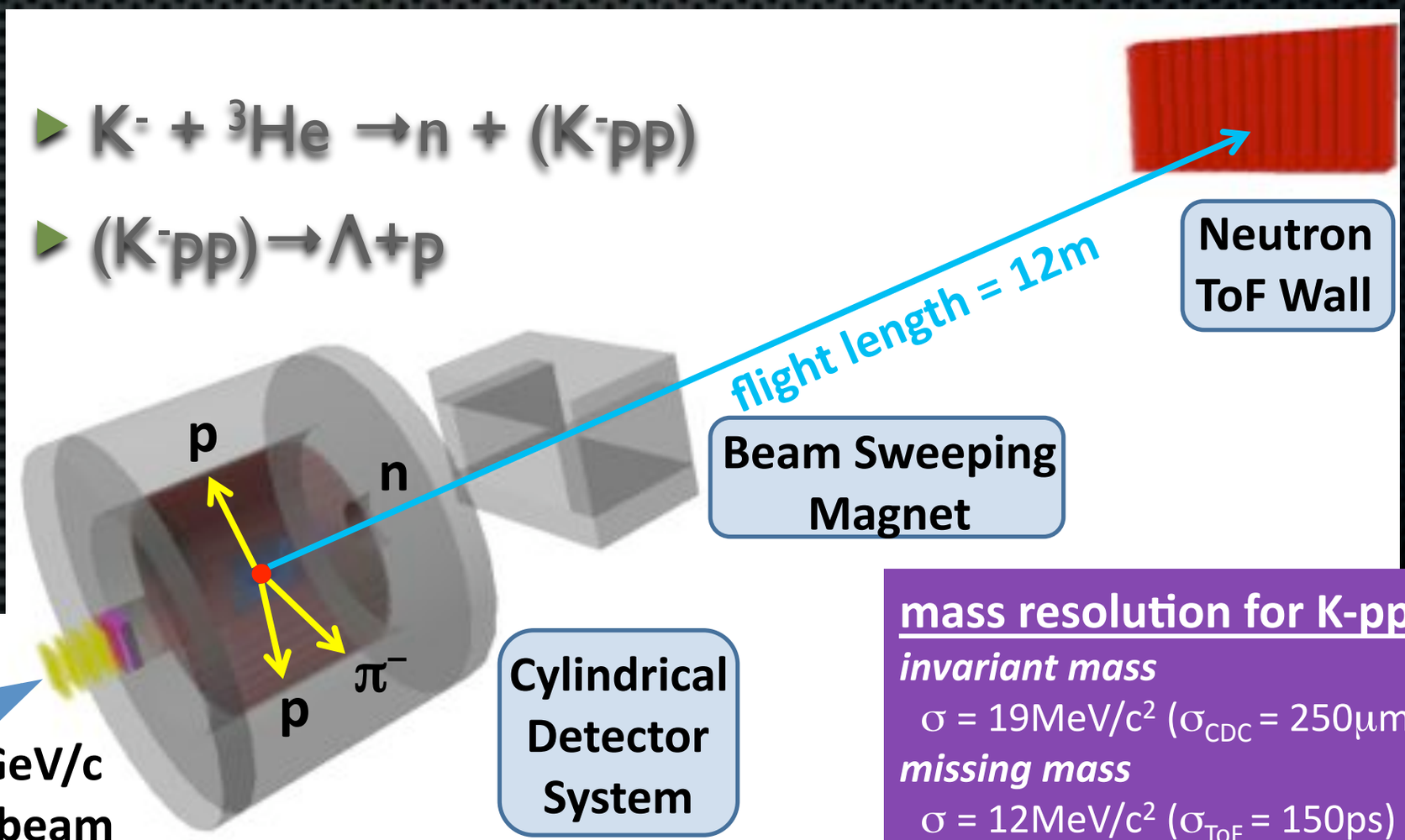


K^-pp search experiments at J-PARC

- $^3He(K^-,n)$ reaction at 1 GeV/c: E15
- $d(\pi^+,K^+)$ reaction at 1.5 GeV/c: E27



- $K^- + {}^3He \rightarrow n + (K^-pp)$
- $(K^-pp) \rightarrow \Lambda + p$



mass resolution for K-pp

invariant mass

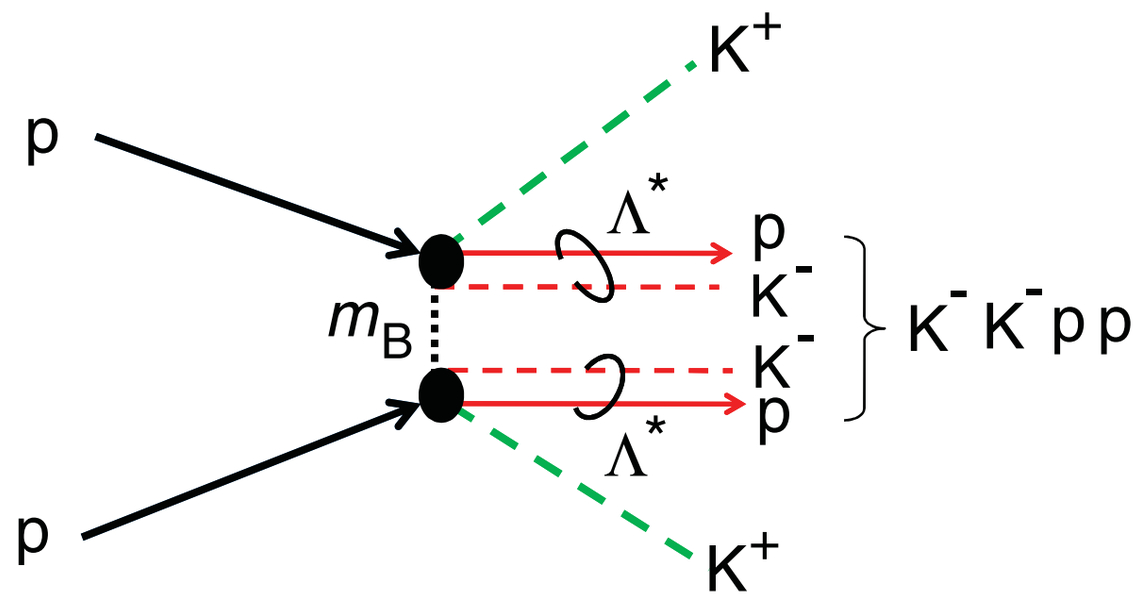
$\sigma = 19 MeV/c^2$ ($\sigma_{CDC} = 250\mu m$)

missing mass

$\sigma = 12 MeV/c^2$ ($\sigma_{ToF} = 150ps$)

K^-K^-pp

PHYSICAL REVIEW C **84**, 015207 (2011)



Summary

- J-PARC will open a new era for Strangeness Nuclear Physics.
- Day-1 Experiments; data-taking in progress
  - Ξ hypernuclear Spectroscopy
  - Search for Kaonic Nuclei
  - γ-ray spectroscopy, Neutron-rich hypernuclei
  - H search exp. (P42) is proposed.